FINAL SUMMARY
REPORT

MSFC CONTRACT
NAS 8-20661

ATM CMG/EPEA
1975

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INTRODUCTION

During the eight year period from December 1966 through December 1974, The Bendix Guidance Systems Division (BGSD) of The Bendix Corporation developed and delivered to Marshall Space Flight Center (MSFC) several items of Skylab/Apollo Telescope Mount (ATM) Control Moment Gyro (CMG) equipment and ATM Control Computer and Experiment Pointing Electronic Assembly equipment (ATMCC and ATM EPEA) under contract NAS 8-20661.

The contract equipment included all breadboard, engineering, qualification, flight and spare units, appropriate shipping containers, all in-process and final test equipment including deliverable final test stands, and the necessary tools and fixtures. In addition, the contract provided for MSFC support at BGSD and in Huntsville, Alabama, as well as at Johnson Spaceflight Center (JSC) in Houston, all throughout the required pre-flight, launch and orbital mission periods.

The ATM CMGs, with their respective Inverter Assemblies (IA), were used as the momentum exchange actuators controlling the entire Skylab orbital assembly. Section 1 reports on this equipment.

At the outset of the contract, the ATM CC was to provide analog processing electronics between sensors and actuators for total spacecraft control as well as for on-board gimballed experiment package control. As the program progressed, MSFC decided to split these two control functions into two separate equipments. Accordingly, a major contract modification deleted the spacecraft control function and left the experiment pointing control function. As a result, the ATM CC was deleted and the ATM EPEA was defined. The EPEA was able to use much of the circuitry and packaging that was designed, developed and constructed for the CC. Section 2 reports on this equipment.

During the contract, BGSD delivered documentation in the form of drawings and specifications (including microfilm), technical memorandums, design review presentations and monthly progress reports. This report is the Final Contract Summary Report.

SECTION 1

ATM CMG SUBSYSTEM

1.1 GENERAL

During the course of this portion of the contract, 12 Double Gimballed Control Moment Gyros (DGCMG) and their associated electronics were provided. Changes and fixes were incorporated and retrofitted in the same 12 subsystems as the program evolved resulting in two hardware detailed configurations and use as follows:

Serial No.	Configuration	Use
1, 2, 3	Engineering	Hardware Sim. Lab (HSL)
4	Flight	Qualification
5-12	Flight	Skylab Mission: CMG SN 5, 6, 7 IA SN 8, 9, 12 Flight Backup ATM: CMG SN 8, 9, 12 IA SN 5, 6, 7 Bonded Stores (MSFC): CMG SN 10, 11 IA SN 10, 11

Flight configuration spare component hardware, to facilitate retrofit cycles as well as a spares program, included CMG Actuator (torquer) pivot assemblies, CMG sensor pivot assemblies, CMG cables, electronic modules and various piece parts deemed necessary for program support.

The major elements of engineering hardware were provided for spin bearing life testing, actuator life test and Inverter Assemblies (IA) needed to support the HSL during a major configuration change to increase the angular momentum (speed) of the CMG wheel. The IAs designated SN A, B, C were used in the HSL until SN 1, 2, 3 were retrofitted as required. The life test hardware was ultimately assigned as follows:

Item*	Ultimate Assignment
IGRA E1	transferred to contract NAS 8-25756
IGRA E2	transferred to contract NAS 8-31236
IGRA E3	same
LTF 2-6	same
LTF 1	at MSFC
3 actuators	at MSFC

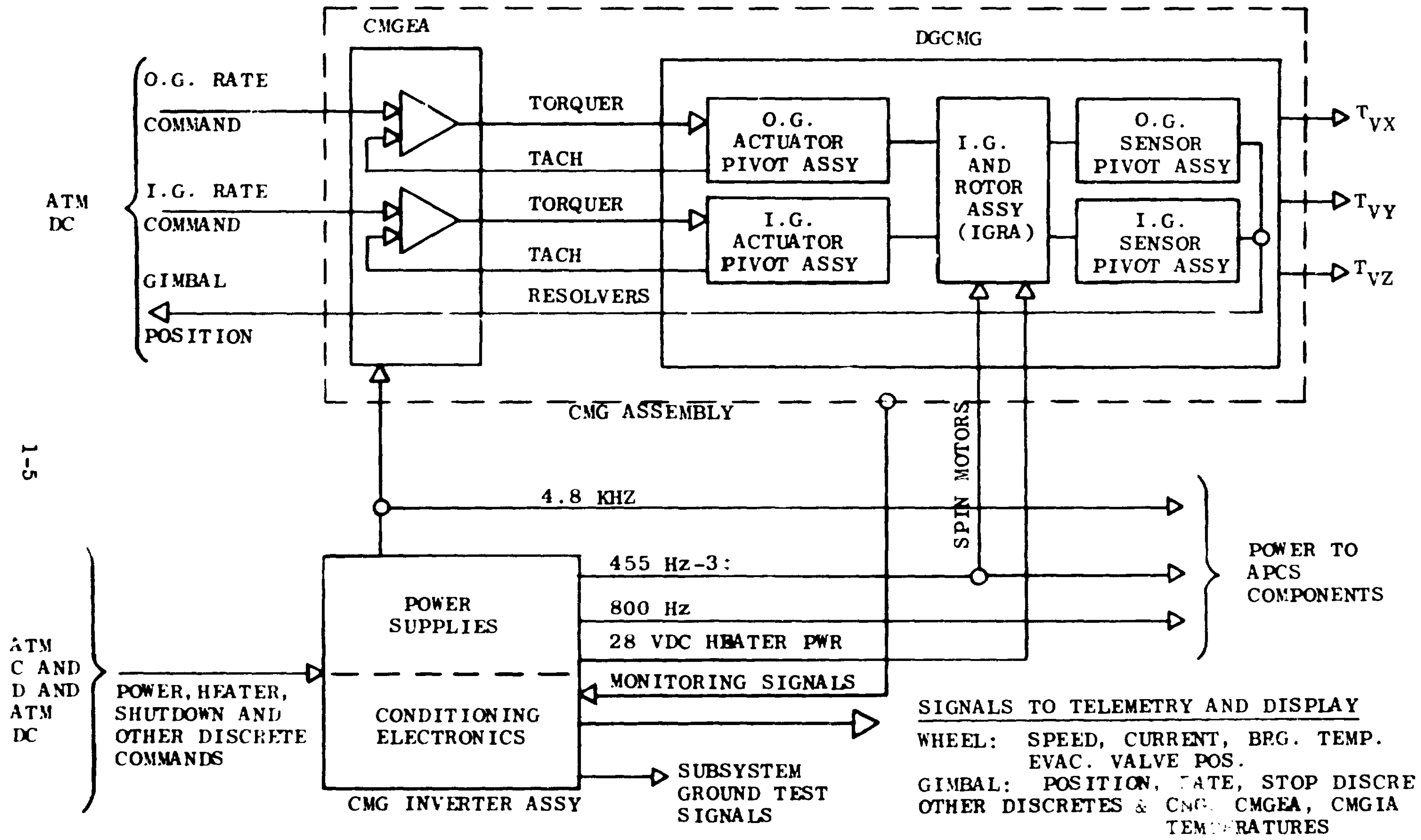
*IGRA = Inner Gimbal and Rotor Assembly
LTF = Spin bearing life test fixture

The descriptive material that follows deals primarily with the flight configuration equipment and life testing.

1.2 SUBSYSTEM DESCRIPTION

Basically, the ATM Double Gimballed CMG (DG CMG) is a gyro wheel (rotor), spin motors and spin bearings assembly mounted in a vacuum inner gimbal cavity which is mounted in an outer gimbal which in turn is mounted in a frame and cover base assembly. The inner gimbal, outer gimbal and frame are interconnected by pivots on gimballing axes. Each of the two gimbal axes contains a set of bearings, a resolver assembly and flex leads in a housing to form a Sensor Pivot Assembly on one side of the axis and a set of bearings, a torquer, a tachometer and a gear package in a housing to form an actuator pivot assembly on the other side of the axis. Electrical cables and mechanical gimbal stops are mounted on the gimbals and frame. A gimbal drive servo electronics box is mounted externally on the CMG frame. Photographs of the CMG and its subassemblies are displayed in section 1.4. An Inverter Assembly (CMG IA) is supplied with each CMG to form one CMG Subsystem. This separate electronics box furnishes AC power, control circuits and conditioning electronics for Telemetry as well as Display on the ATM Control and Display Console.

A functional block diagram of the CMG Subsystem is shown in Figure 1.2-1. Wheel control is provided open loop by a 455 Hz, 3 phase inverter driving two AC spin motors in parallel. The spin motors are each 9 oz-in, 6 pole, dual cage induction motors designed to provide high starting torque, a relatively constant accelerating torque and a high torque/speed slope near synchronous speed in order to provide good speed regulation under varying spin



C AND D = CONTROL AND DISPLAY CONSOLE

DC = DIGITAL COMPUTER

ATM CMG SUBSYSTEM FUNCTIONAL BLOCK DIAGRAM

FIGURE 1.2-1

bearing friction and vacuum cavity windage drag load. With the 455 Hz inverter, the wheel synchronous speed is 9100 rpm and its nominal operating speed is 9000 rpm. (The original configuration, before contract change, was 400 Hz, 8000 rpm and 7850 rpm, respectively). During the Skylab mission the operating speeds were indicated by telemetry to be in the range of approximately 8800 rpm to 9100 rpm considering all three flight units. Other wheel control functions include spin bearing heater control and a manual as well as automatic wheel shutdown. These control function circuits are located in the CMGIA. Automatic thermostatic control of the spin bearing temperature between 60°F and 80°F is provided using thermistor sensors on the spin bearings, control circuits in the IA and heater elements at the spin bearings. Manual wheel shutdown at anytime or automatic wheel shutdown at an indicated spin bearing temperature of 200°F was provided in IA circuits selected by external subsystem switches. Astronaut override of automatic shutdown was provided for. The shutdown function caused disconnect of the 3 phase inverter output lines from the spin motors and the connection of a low voltage dc supply to pass direct current through one pair of spin motor lines causing a braking torque to be generated by the motors. Wheel monitoring signals for telemetry and display are provided as listed on Figure 1.2-1. Wheel cavity vacuum and spin bearing vibration sensors are provided for ground test monitoring along with many other subsystem ground test signals.

Gimbal rate control is provided by a geared drive brush type torquer and tachometer with analog rate loop electronics located in the CMG Electronics Assembly (CMGEA). Limited gimbal freedom is provided through the use of energy absorbing gimbal stops and flex leads for signal and power transmission across the gimbal pivots. Gimbal angle readout 4.8 KHz signals are provided by single speed wound resolvers for ATM Digital Computer use in momentum management computations as well as for telemetry and display. All telemetry and display signals for gimbal control are provided as listed on Figure 1.2-1.

An additional major function provided by the CMG Subsystem equipment is to provide certain ac power from the CMGIA to other equipment in the ATM Attitude and Pointing Control System (APCS). As shown on Figure 1.2-1, these include 800 Hz, 455 Hz (3 phase) and 4.8 KHz power.

The major interfaces of the ATM CMG Subsystem, as shown on Figure 1.2-1, include the ATM Digital Computer for gimbal rate command and gimbal angle readout, the ATM DC and C and D for power and other switch controls, Telemetry and Displays, AC power for other APCS equipments and output torque on the vehicle. The key physical and performance characteristics of the subsystem are summarized in Tables 1.2-1 and 1.2-2.

SKYLAB/ATM CMG SUBSYSTEM

EXTERNAL PHYSICAL CHARACTERISTICS

CMG		CMGIA	
MODEL:	NASA P/N 50M22136 Bendix P/N 2120100	MODEL:	NASA P/N 50M22137 Bendix P/N 2121500
SIZE:	39" X 41 7/8" X 38 5/8"	SIZE:	25" X 22 1/2" X 3 1/2"
WEIGHT:	418 Lbs.	WEIGHT:	49 Lbs.
MOUNTING:	Four Point C.G.	MOUNTING:	16 Point Bolt Attach.
EXTERNAL FINISH:	Pyromark (White)	EXTERNAL FINISH:	Pyromark (White)
	$e = 0.9$ Nom.		$e = 0.9$ Nom.
	$\alpha = 0.25$ Max.		$\alpha = 0.25$ Max.

SUBSYSTEM WEIGHT: 467 Lbs. (One CMG and IA)

TABLE 1.2-1

SKYLAB/ATM CMG SUBSYSTEM CHARACTERISTICS

Stored Angular Momentum		2300 ft-lb-sec
Maximum Output Torque (Simultaneous 2 gimbals)		122 ft-lb
Degrees of Freedom		2
Maximum Gimbal Rate	Inner Gimbal	4 deg/sec
	Outer Gimbal	7 deg/sec
Gimbal Rotation (Mech. Stops)	Inner Gimbal	± 80 deg.
	Outer Gimbal	± 175 deg.
Bandwidth (Over Gimbal Angle Range and over 0.2 deg/sec to 3.5 deg/sec comm. range)		4 HZ to 10 HZ
Power at Nominal 28V. line (on orbit)		
Wheel Spin Control (2 motors)	- at Speed	80 Watts
	- Spin Up peak	170 Watts
	- DC Brake	28 Watts
Gimbal Control - Both at 3.5 deg/sec - peak		170 Watts
Spin Bearing Heater Control - peak		52 Watts
Other Inverter Assembly Functions - peak		70 Watts
Wheel Spin Up Time (28 V. Line)		14 hrs. max.
Wheel Decelleration Time (DC Braking)		5 hrs. max.

IGRA:

Rotor	Rimmed Disk of Maraging Steel
Rotor Diameter	22 in.
Rotor Weight	145 lbs.
Rotor Operating Speed (Synch. Speed 9100 RPM)	9,000 RPM
Spin Motor	2 Three Phase Dual Cage Induction Motors.

Monitors:
- Bearing Thermistors
- Wheel Speed
- Cavity Pressure for Ground Test Use
- Bearing Vibration for Ground Test Use

Each Actuator Pivot Assembly:

Gear Ratio	56.6 to 1
Torque Motor (Brush Type)	Inland T5793A, 7 ft-lb
Tachometer (Brush Type)	Inland TG2815A, 1V./Rad./Sec.

Each Sensor Pivot Assembly:

Flex Leads	
Gimbal Position Pickoff	3 Resolvers
Gimbal Excursion Limit Switches	

TABLE 1.2-2

1.3 QUALIFICATION TESTING

The ATM CMG Subsystem qualification testing was conducted by NASA MSFC using MSFC facilities as well as Wyle Laboratories/Testing Division facilities at Huntsville, Alabama. The subsystem was qualified to the requirements of MSFC document 50M22162B, "Environmental Qualification Test Specification and Procedures for the Control Moment Gyro System for ATM" which contains all qualification requirements of the ATM basic test criteria document 50M02408D "Environmental Design and Test Criteria for ATM Components".

MSFC document 50M22163 is the Summary Environmental Qualification Test Report and Wyle documents 17017-1 and 42078-1 document specifications, procedures and test reports for the portion of tests conducted at Wyle Labs.

Certification of qualification for flight was provided by the MSFC S and E-ASTR-GSQ design laboratory.

The following tabulations present the qualification environments.

ATM CMG SUBSYSTEM ENVIRONMENTS
(NOTE: UNITS LOCATED ON ATM CRACK-EXTERIOR OF SPACECRAFT)
QUALIFICATION

	CMG	CMGIA
GROUND CONDITIONS		
HIGH TEMP.	+74°C SOAK +38°C OPERATING	+74°C SOAK +74°C OPERATING
LOW TEMP.	-48°C SOAK 0°C OPERATING	-48°C SOAK -48°C OPERATING
THERMAL SHOCK	74°C, -48°C, 74°C 3 CYCLES; 5 MIN. BETWEEN SOAK TEMPS.	74°C, -60°C, 74°C 3 CYCLES; 5 MIN. BETWEEN SOAK TEMPS.
HUMIDITY	5 CYCLES: 38°C, 50% R.H. FOR 6 HRS. 5 HRS. TO 25°C AND R.H. TO 100% 8 HRS. TO 21°C WITH RELEASE OF WATER 4 HRS. TO 38°C AND R.H. TO 41% 1 HR. AT 38°C AND R.H. TO 50%	SAME AS CMG
MECHANICAL SHOCK	15g. PEAK, 10 MS., HALF SINE	15g. PEAK, 10 MS., HALF SINE
LAUNCH-BOOST CONDITIONS		
ACOUSTIC VIB.	TABLE I	TABLE I
ACCELERATION	8g. ANY AXIS	10g ANY AXIS
VIBRATION	TABLE II	TABLE II

TABLE 1.3-1

ATM CMG SUBSYSTEM ENVIRONMENTS

QUALIFICATION

		CMG	CMGIA
FLIGHT CONDITIONS			
THERMAL VACUUM:			SAME AS CMG.
HOT EXTREME	-	PRESSURE: 1 X 10^{-6} MMHG. EFF. HEAT SINK: 35°C	
COLD EXTREME	-	PRESSURE: 1 X 10^{-6} MMHG EFF. HEAT SINK: -62°C*	
RFI		MIL-I-6181D	MIL-I-6181D

*POWER TURNED ON PRIOR TO LOWERING TEMPERATURE

TABLE 1.3-1 (CONTINUED)

ACOUSTICAL - VIBRATION ENVIRONMENTS

TABLE I. Acoustical

Major zone: Payload, internal, to shroud

One-third octave band acoustical specification in db re: 2×10^{-4} dynes/cm^2

Test duration: High level - 2.0 minutes
Low level - 1.0 minute

One-third octave band geometric mean freq. (cps)	Internal Sound Pressure High Level (db)	Internal Sound Pressure Low Level (db)
5.0	138.5	118.0
6.3	140.0	121.0
8.0	141.5	124.0
10.0	142.5	126.5
12.5	143.5	128.0
16.0	144.5	129.5
20.0	145.5	131.5
25.0	146.0	133.0
31.5	146.0	134.5
40.0	146.5	135.5
50.0	146.5	136.5
63.0	146.0	137.5
80.0	145.5	138.5
100.0	143.0	139.0
125.0	140.0	138.0
160.0	136.0	135.0
200.0	132.5	133.0
250.0	130.0	131.0
315.0	128.0	129.0
400.0	124.0	126.0
500.0	121.0	123.0
630.0	118.0	120.0
800.0	115.0	117.0
1000.0	112.0	113.5
1250.0	109.0	110.0
1600.0	105.5	106.0
2000.0	102.5	102.5
2500.0	99.0	99.0
3150.0	95.0	95.0
4000.0	92.0	91.5
5000.0	89.0	87.5
6300.0	85.0	84.0
8000.0	81.0	80.0
10000.0	78.0	76.0
Overall sound pressure level	156.5	147.0

TABLE 1.3-1 (CONTINUED)

TABLE II - VIBRATION

A. Specification 2-Input to -Z, +Z, and -Y CMG, Mounting Lugs of Rack Mounted Control Moment Gyros (CMG)

1. Vehicle Dynamics Criteria

   Flight Axis (5-30 Hz @ 3 oct/min)

5-	13 Hz	@	.29 Inches D.A. Disp.
13-	30 Hz	@	2.5 g's peak

   Lateral Axis (5-30 Hz @ 3 oct/min)

5-	12 Hz	@	.20 Inches D.A. Disp.
12-	30 Hz	@	1.5 g's peak

2. Sine Evaluation Criteria (20-2000 Hz @ 1 oct/min)

20-	90 Hz	@	.0024 Inches D.A. Disp.
90 -	2000 Hz	@	1.0 g's peak

3. High Level Random Criteria (1 min/axis)

	20 Hz	@	.000040 g^2/Hz
20-	90 Hz	@	+ 9 dB/oct
90-	140 Hz	@	.0036 g^2/Hz
140-	360 Hz	@	+ 9 dB/oct
360-	460 Hz	@	.065 g^2/Hz
460-	2000 Hz	@	-12 dB/oct
	2000 Hz	@	.00018 g^2/Hz

Composite = 4.7 grms

4. Low Level Random Criteria (4 min/axis)

	20 Hz	@	.0000050 g^2/Hz
20-	90 Hz	@	+ 9 dB/oct
90-	140 Hz	@	.00047 g^2/Hz
140-	360 Hz	@	+ 9 dB/oct
360-	460 Hz	@	.0086 g^2/Hz
460-	2000 Hz	@	-12 dB/oct
	2000 Hz	@	.000025 g^2/Hz

Composite = 1.7 grms

5. Shock Criteria - Flight

   No shock test required

TABLE 1.3-1 (CONTINUED)

TABLE II - VIBRATION - SPECIFICATION R - 3 - C

B. CMGIA Criteria

Input to components mounted on ATM Honeycomb Shear Panel (Quarter Panel). Total weight of components per panel greater than 100 pounds but less than 200 pounds

1. Vehicle Dynamics Criteria

Flight Axis (5-30 Ha @ 3 oct/min)

5- 13 Hz @ .29 Inches D.A. Disp.
13- 30 Hz @ 2.5 g's peak

Lateral Axes (5-30 Hz @ 3 oct/min)

5- 12 Hz @ .20 Inches D.A. Disp.
12- 30 Hz @ 1.5 g's peak

2. Sine Evaluation Criteria (20-2000 Hz @ 1 oct/min)

20- 90 Hz @ .0033 g^2/Hz
2000 Hz @ 1.3 g's peak

3. High Level Random Criteria (1 min/axis)

20 Hz @ .00030 g^2/Hz
20- 90 Hz @ + 9 dB/oct
90- 150 Hz @ .023 g^2/Hz
150- 285 Hz @ + 9 dB/oct
285- 500 Hz @ .15 g^2/Hz
500- 2000 Hz @ -12 dB/oct
2000 Hz @ .00059 g^2/Hz

Composite - 8.3 grms

4. Low Level Random Criteria (4 min/axis)

20 Hz @ .000070 g^2/Hz
20- 90 Hz @ + 9 dB/oct
90- 150 Hz @ .0058 g^2/Hz
150- 285 Hz @ + 9 dB/oct
285- 500 Hz @ .038 g^2/Hz
500- 2000 Hz @ -12 dB/oct
2000 Hz @ .00015 g^2/Hz

Composite - 4.2 grms

5. Shock Criteria - Flight

No shock test required

TABLE 1.3-1 (CONTINUED)

1.4 MAJOR ASSEMBLIES OF THE CMG SUBSYSTEM

1.4.1 CMG Assembly Description

1.4.1.1 CMG Assembly, General Description

The CMG (Bendix P/N 2120100-29) is a double gimballed unit consisting of a sealed Inner Gimbal and Rotor Assembly (IGRA) mounted in an outer gimbal which in turn is mounted in the CMG frame.

The IGRA, with the Evacuation Valve mounted, is supported in the outer gimbal by the Inner Actuator and Inner Sensor which, with the IGRA cable assembly, make up the Outer Gimbal Assembly. This assembly, after being statically balanced about its axis of rotation, is supported in the CMG frame by the Outer Actuator and Outer Sensor.

The Gimbal Servo Electronics Assembly, which provides the electrical interface to the CMG, and an elapsed time indicator, which records the number of hours of CMG operation, are mounted externally on the frame. The final CMG assembly also includes cable assemblies that carry electrical power and signals across the gimbals, bumper stops that limit both inner and outer gimbal rotation and the upper and lower CMG covers.

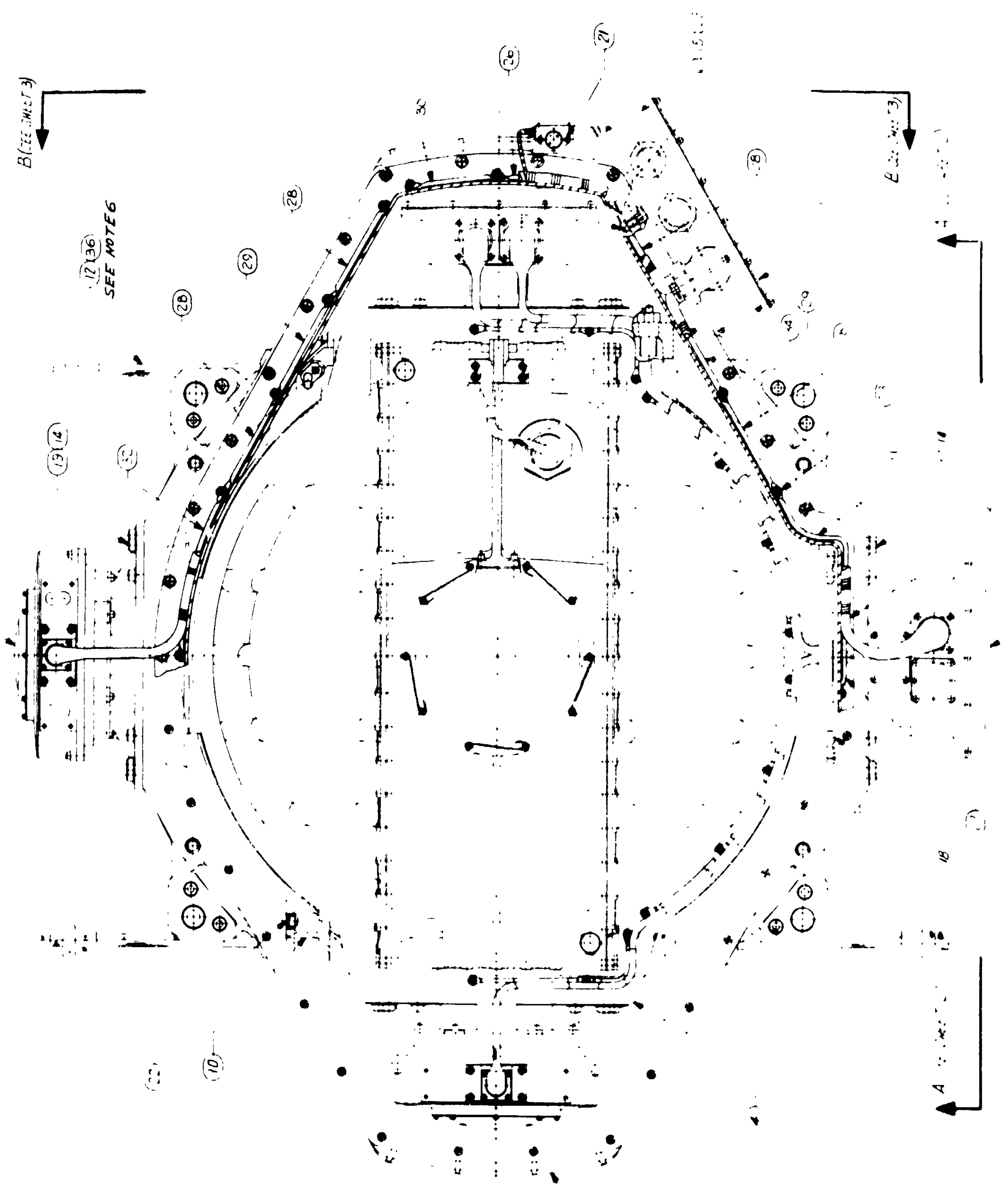
To meet MSFC requirements for low solar absorbtance (α) and high emittance (ϵ), all external surfaces of the CMG are finished with Pyromark White paint (α = 0.25 max, ϵ = 0.90 nom). The CMG also includes, as an additional thermal barrier, an aluminized mylar cover, assembled to the unit by Velcro pads and lacing.

For protection of the CMG during shipment, means are provided to cage the IGRA, the outer gimbal and the frame to each other. Caging bushings in these members are accurately located and bored to engage caging pins that are retained by spring loaded detents.

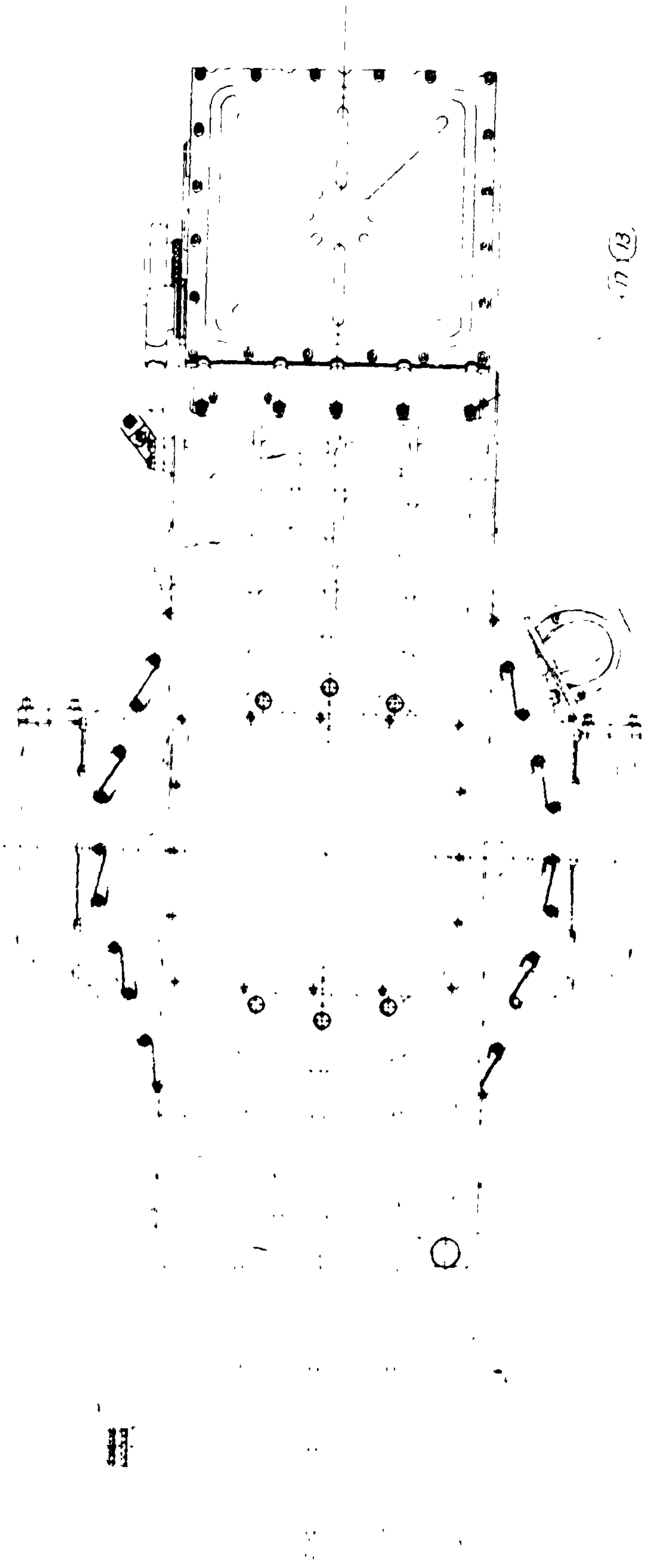
Mechanical interface with the ATM rack is provided by four mounting feet located at the unit C.G. Each of the four feet has accurately sized and located holes for one shoulder bolt and two locating dowels. Templates for checking the size and location of these holes were fabricated by Bendix to dimensional information supplied by MSFC. One such template was retained by Bendix for use in the final mechanical inspection of each CMG delivered. A duplicate template was sent to MSFC for use as a check for both the CMG and the ATM rack.

Total weight of the CMG is 418 lbs. The CMG assembly is shown in Figure 1.4.1.1-1. Mechanical interface and envelope information is given in MSFC drawing 50M22136. Figure 1.4.1.1-2 shows the fully assembled CMG and Figure 1.4.1.1-3 shows the unit with the top cover removed.

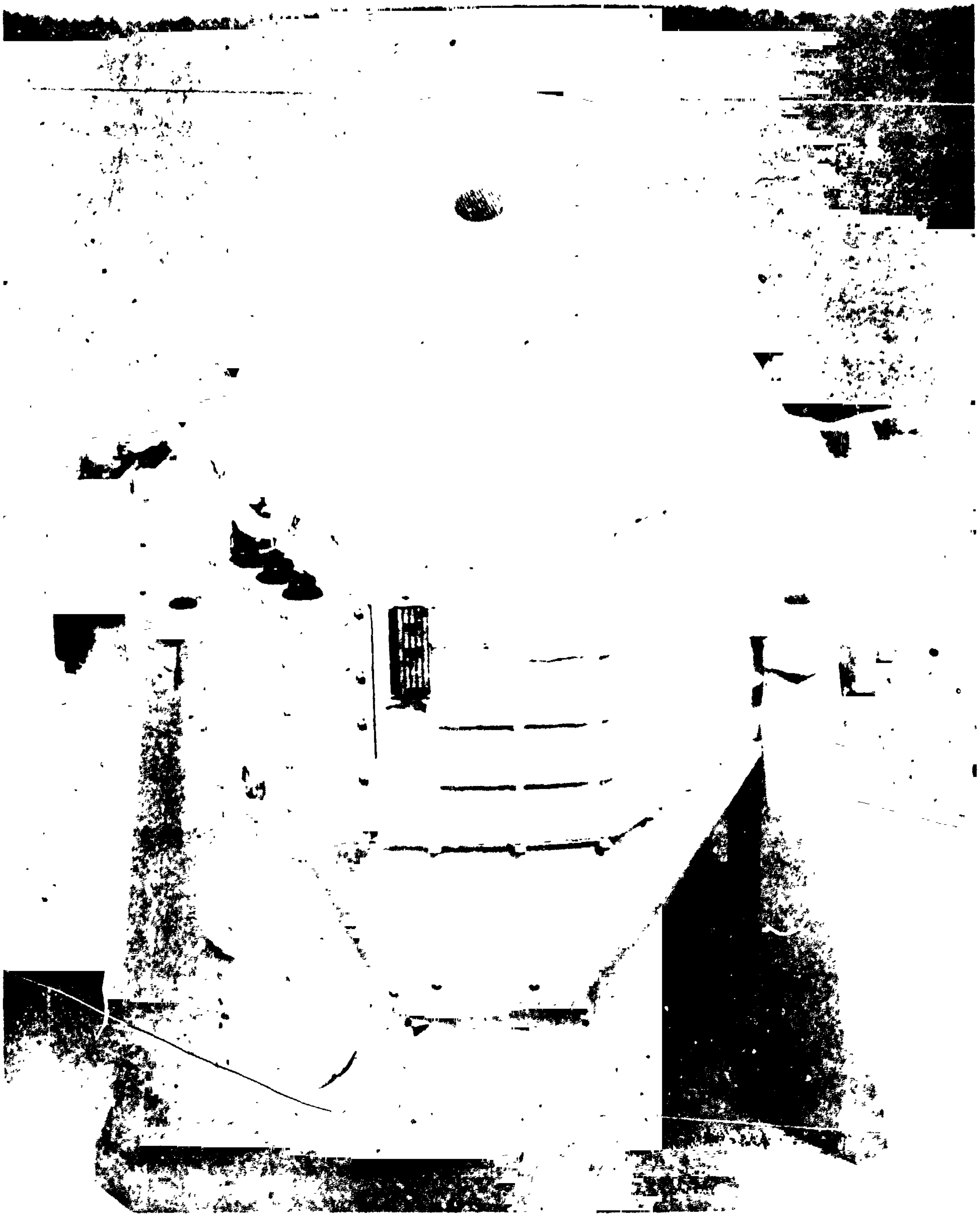
The features of major components of the CMG are discussed in detail in the following sections.



CMG ASSEMBLY
FIGURE 1.4.1.1-1
(SHEET 1)



CMG ASSEMBLY
FIGURE 1.4.1.1-1
(SHEET 2)



ATM CMG
FIGURE 1.4.1.1-2

ATM CMG (TOP FRAME COVER OFF)
FIGURE 1.4.1.1-3

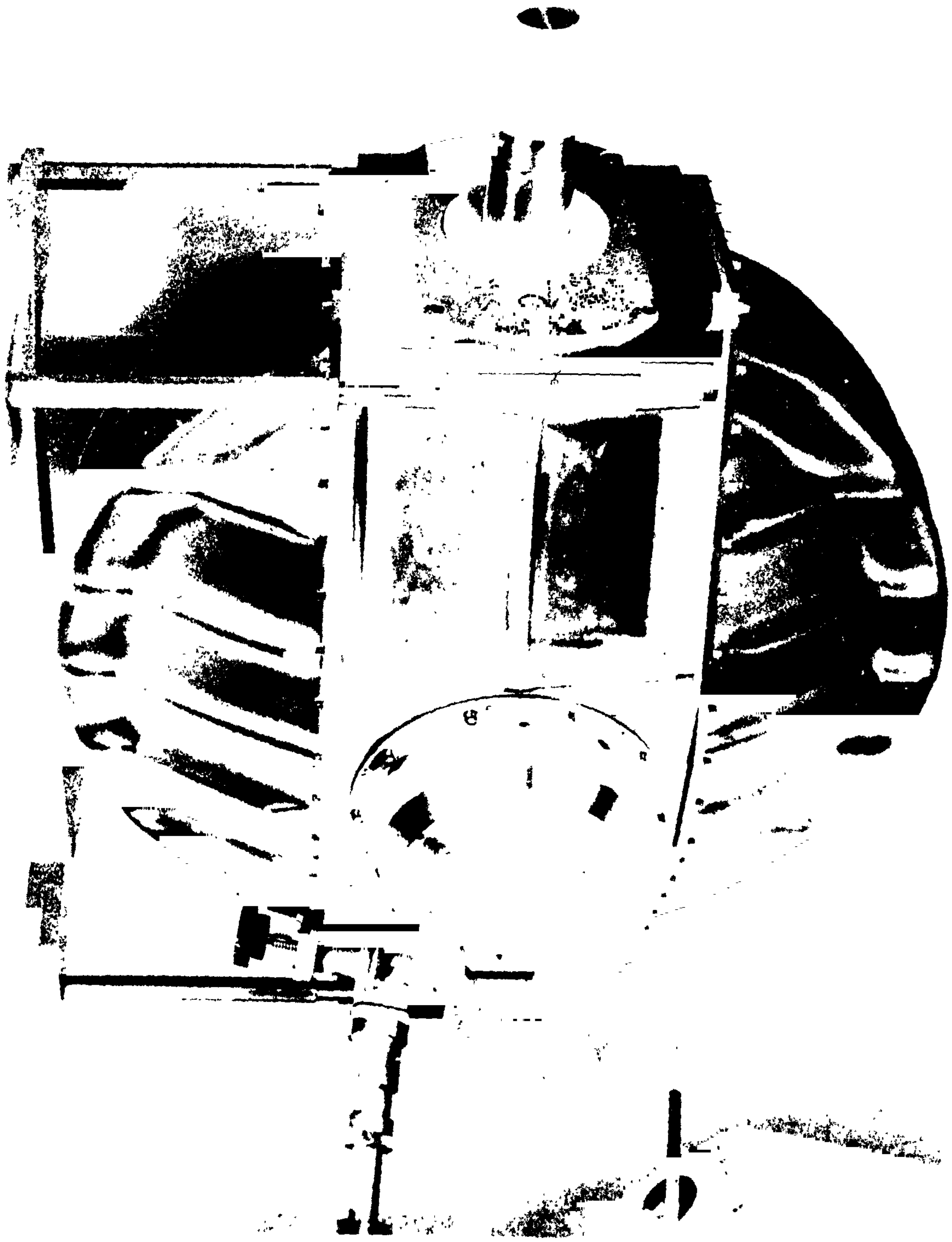
1.4.1.2 Inner Gimbal and Rotor Assembly (IGRA)

The inner gimbal and rotor assembly of the ATM CMG is an evacuated package containing the rotor with its support bearings, the bearing lubrication system, the spin motors, heaters. and performance monitoring devices. Figure 1.4.1.2-1 is a physical picture of the Inner Gimbal and Rotor Assembly.

The unit develops an angular momentum of 2300 ft-lb-sec by employing a single piece 22 inch diameter type 300 maraging steel wheel weighing 145 lbs. and rotating at a nominal speed of 9000 RPM.

Two special 107 size, deep groove angular contact ball bearings with custom designed phenolic retainers sustain the wheel in its support housing. Preload is accomplished by the use of low spring rate belleville springs set to 40 lbs. These springs allow for growth to accommodate thermal gradients.

The bearing support system includes a slider and cartridge assembly as well as a steel temperature compensating thru strut. The strut, which has the same coefficient of thermal expansion as the wheel, and is much stiffer than the gimbal, is rigidly attached to the gimbal at both bearing ends. This forces the gimbal to assume a coefficient of thermal expansion close to that of the wheel. Coupling this with the spring clearance insures a constant preload over the entire thermal operating range of the CMG ($-65^{\circ}F$ to $+180^{\circ}F$).



INNER GIMBAL AND ROTOR ASSEMBLY (IGRA)
FIGURE 1.4.1.2-1

The support system mounts into an elliptical flanged, rectangular ribbed inner gimball which is machined out of a 6061 aluminum forging.

This gimbal was machined rather than cast in order to assure minimum gas leakage through the aluminum. The gimbal is of one piece construction and is line bored for accurate alignment of the bearing cartridge assembly. The gimbal surface finish is black anodize. The inner gimbal covers are .060 inch thick semi-ellipsoids which are hydroformed of aluminum. The covers are sealed to the gimbal by the use of two parker seals. Both covers will withstand a pressure differential of two atmospheres.

Bearing lubrication is provided by a dynamic lubricating nut capable of maintaing a lubricant feed in a zero "g" environment. Sufficient lubricant is installed at assembly to carry the unit through greater than 100,000 hours of operating life. KG 80 oil, having an extremely low vapor pressure, is the lubricant employed.

The wheel is driven by a pair of three phase wye connected 455 Hz, double squirrel cage induction motors having a synchronous speed of 9100 RPM. The dual cage provides high starting torques and optimum running power.

In consideration of the intended environment, the Inner Gimbal Assembly is equipped with bearing heaters for bearing temperature preconditioning during low temperature starting.

The unit is equipped with ground test monitoring accelerometers for measuring bearing vibration attendant to wheel operation. Bearing temperature is measured by thermistors and can be used as an indication of bearing degradation. These signals are provided to telemetry by the Inverter Assembly and can be used in automatic shutdown circuitry at the astronaut's option.

The unit is provided with a magnetic wheel speed pickoff developing 30 pulses per revolution. These pulses are subsequently conditioned in the Inverter Assembly to provide DC wheel speed readings for astronaut display and telemetry. As an added feature, three differently shaped pulses are used to indicate the direction of rotation of the wheel.

The Inner Gimbal and Rotor Assembly is equipped with a Thermopile Vacuum probe to allow monitoring of Inner Gimbal Vacuum during ground test. The device is not intended for use during orbital operation.

Full volume modular seals are used to provide a suitable vacuum environment within the inner gimbal cavity.

The inner gimbal and rotor assembly is equipped with a remote operated evacuation valve used for sealing the inner gimbal cavity. The unit provides the suction port for inner gimbal evacuation. Since achieving operating speed in an earth atmosphere is dependent on maintaining a low inner gimbal pressure (for minimum windage), the evacuation valve is used in the pumping operation. In the orbital mode of operation, the valve is intended to be left open. Thus, the valve is of a poppet and seat design operated by a rotary torque motor connected as a two position actuator. This arrangement allows the actuator to be left in either the open or closed state without an attendant power dissipation.

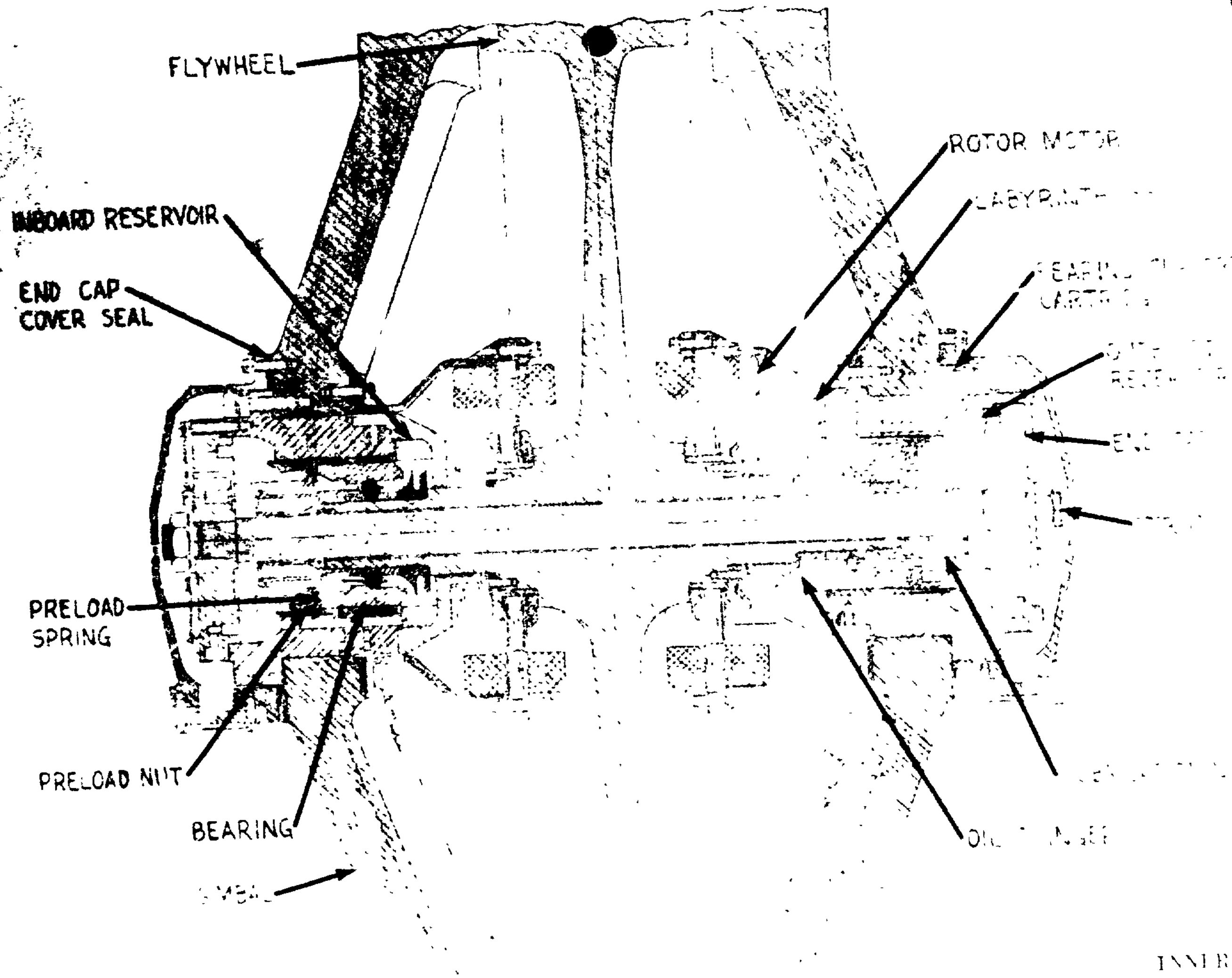
The major component parts of the inner gimbal and rotor assembly are as listed below.

IGRA - MAJOR COMPONENT PARTS

Gimbal
Two Covers
Together these form the wheel cavity.

Evacuation Valve
Pressure Sensor
Rotor (wheel)
Strut
Two 3 Phase AC Dual Cage Spin Motors
Speed Gear and Speed Sensor
Two Spin Bearing and Lubrication System Assemblies
- Spin Bearing
- Preload Spring and Nut
- Dynamic Lub Nut and Reservoir
- Labyrinth Seal
- Oil Slinger
- Felt Excess Oil Reservoirs
- Thermistors
- Accelerometer
- Four Heater Elements

A cross section of the IGRA is shown in Figure 1.4.1.2-2.



INNER GIMBAL
AND ROTOR ASSY.
LAYOUT

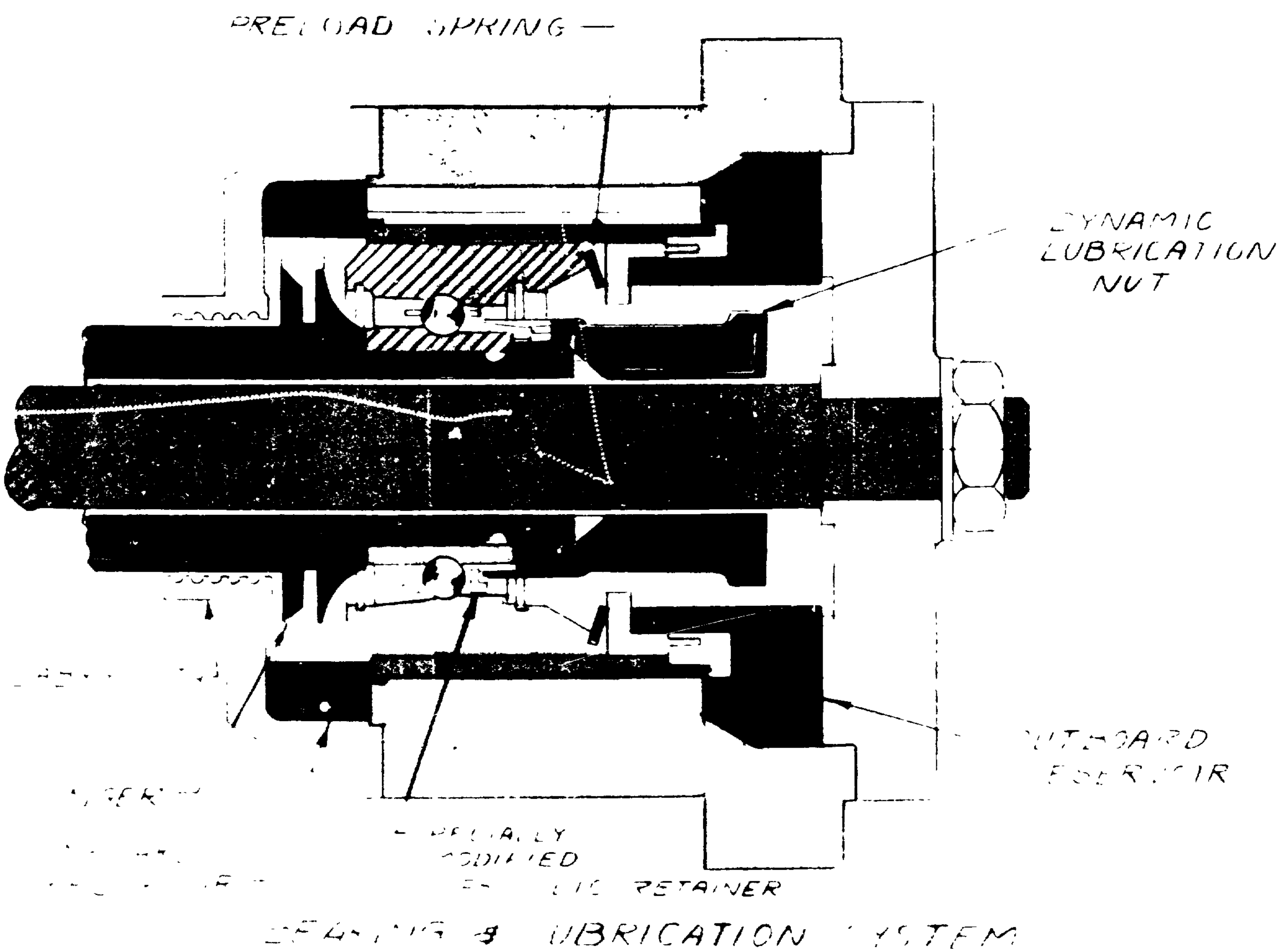
IGRA LAYOUT
FIGURE 1.1.1.2-2

ORIGINAL PAGE IS
OF POOR QUALITY

The rotor is shown with the drive motors mounted on both sides of the flywheel and with each end of the rotor shaft supported on a set of integral slider bearings. These bearings are lubricated with Kendall KG80 oil supplied from the lubrication nut. The complete bearing assembly is mounted in the bearing support cartridge which is rigidly held to the forged aluminum inner gimbal.

The bearing support cartridges are precisely aligned and machined for a controlled clearance between the OD of the bearing and the 52100 cartridge lined bore. This clearance combined with the preload Belleville spring permits free sliding between the rotor-bearing assembly and the gimbal assembly, thus compensating for any thermal expansion. The cartridge and end cap combined with the Maraging strut allows the aluminum gimbal to yield with the forces developed from any thermal expansion or pressure from a one atmosphere environment to a vacuum without causing misalignment of the bearings. The bearing support cartridges are of beryllium for high stiffness and for good heat conductivity. They house the thermistors, heaters and vibration pickoffs.

The bearing and lubrication system is shown in Figure 1.4.1.2-3. To insure the realization of the long life requirement of 10,000 hours, a lubrication make-up system was designed. The dynamic lubrication nut contains 10 gms of oil and is threaded onto the shaft end of the wheel assembly and locks against the inner race face of the bearing. The centrifugal force from rotating with the inner race generates a pressure upon the



BEARING AND LUBRICATION SYSTEM
FIGURE 1.1.1.2-3

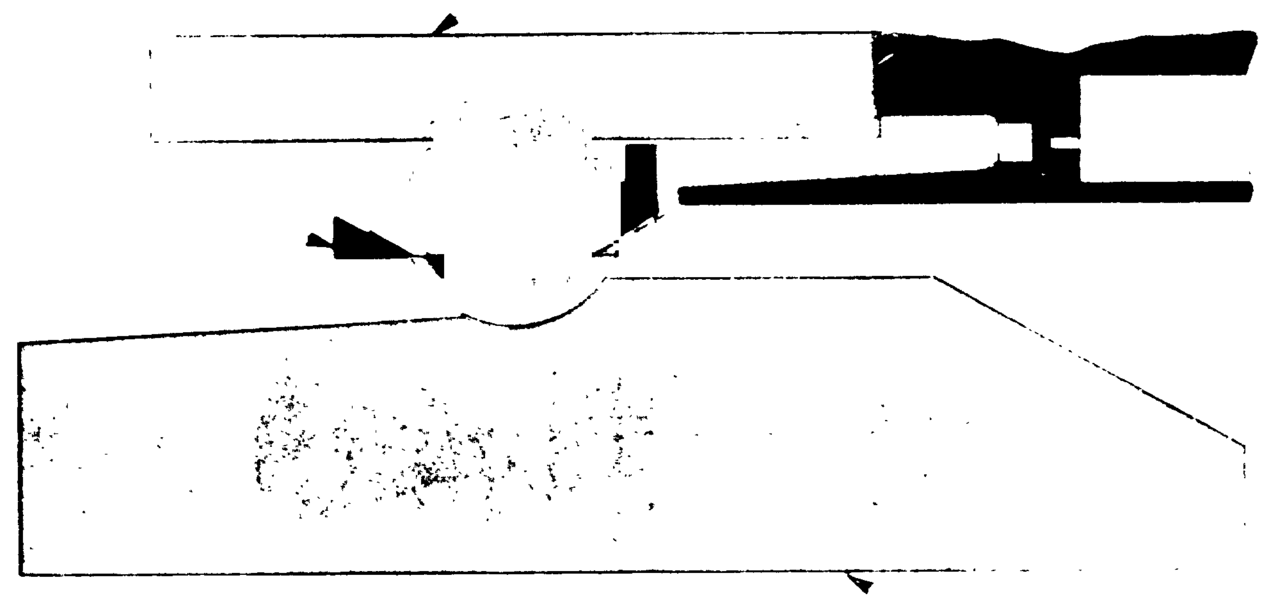
oil within the lubrication nut that forces the oil through a metered port onto the leading edge of the lubrication nut. Centrifugal force carries the oil from the lubrication nut to the bearing retainer. From the retainer under cut, the oil flows through three holes to the contact area of the bearing race ways. The outboard and inboard reservoirs are so located to absorb any excess oil and to act as a vapor type reservoir. Oil which flows through the bearing is slung out to the inboard reservoir by the slinger which rotates with the inner shaft. The labyrinth seal acts as a restrictor and maintains a higher vapor pressure within the bearing cartridge assembly area.

Figure 1.4.1.2-4, Bearing Lubrication Diagram, shows the mechanism of the lubrication system.

1. Centrifugal force, from the rotation of the lubrication nut with the wheel, generates a pressure on the oil in the lubrication nut.
2. The quantity of oil is metered through an orifice within the lubrication nut.
3. The oil passes from the lip of the lube nut onto the retainer undercut.
4. From the retainer, the oil flows through three holes to the contact area of the bearing.

The bearing lubrication can be summarized as follows:

1. Type of system - Dynamic Lubrication Nut
2. Capacity - 10 grams KG-80 oil
3. Flow rate at 90^{o}F(30^{o}C) - 0.10 mg/hr nominal



BEARING LUBRICATION DIAGRAM
FIGURE 1.4.1.2-4

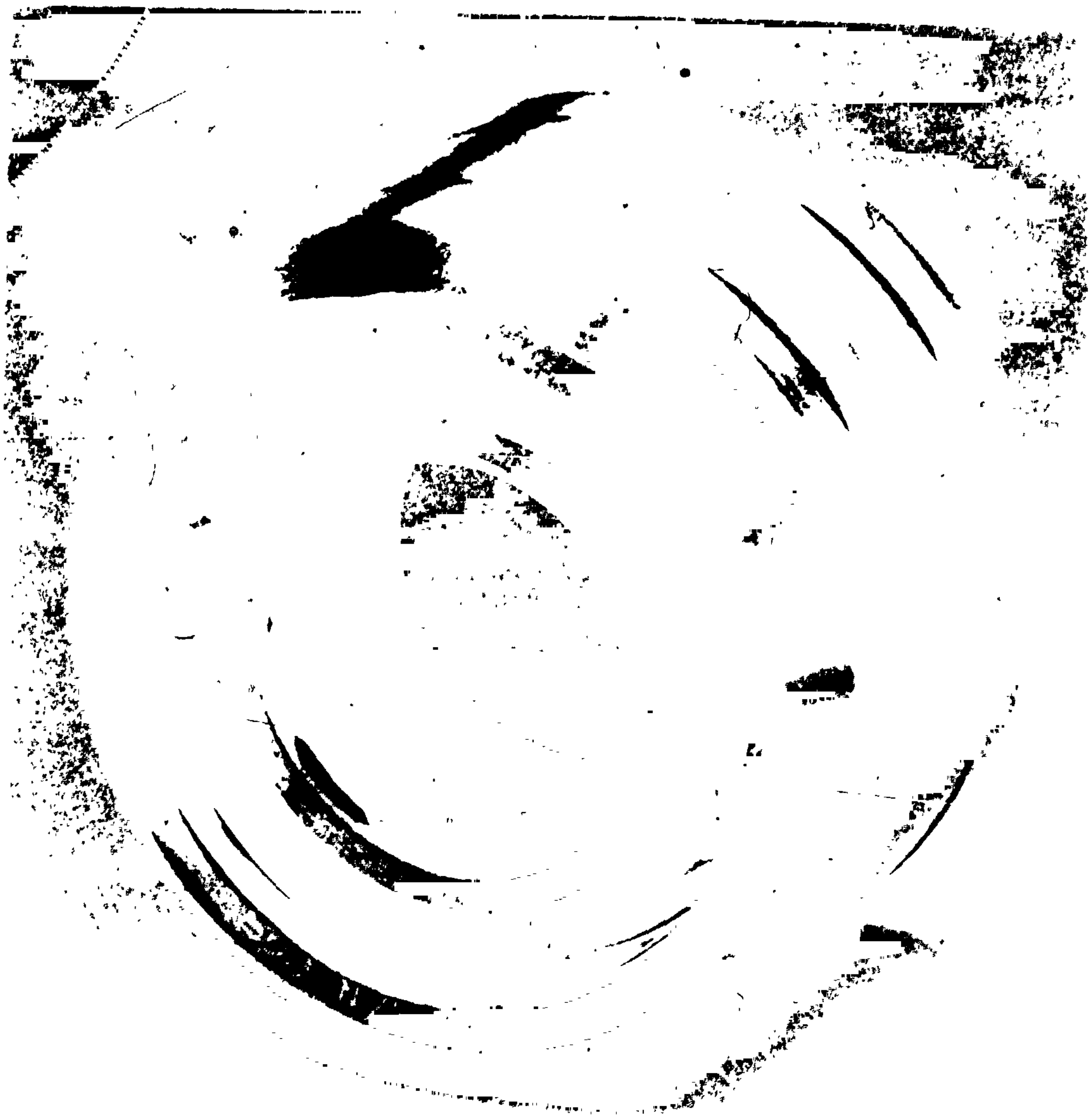
4. Flow Control - Restrictor, Orifice and Fill Quantity
5. Torque penalty - none
6. Thermal compensating
7. "G" Insensitive
8. Lubrication Characteristics (KG80)

Viscosity	160 CS at 100^{o}F
	15.7 CS at 210^{o}F
Viscosity Index	107
Pour Point	+10^{o}F
Flash Point	515^{o}F
Fire Point	600^{o}F
Additives	0.5% A.O.
	1.0% TCP
Vapor pressure	<10-6 TORR at 100^{o}F

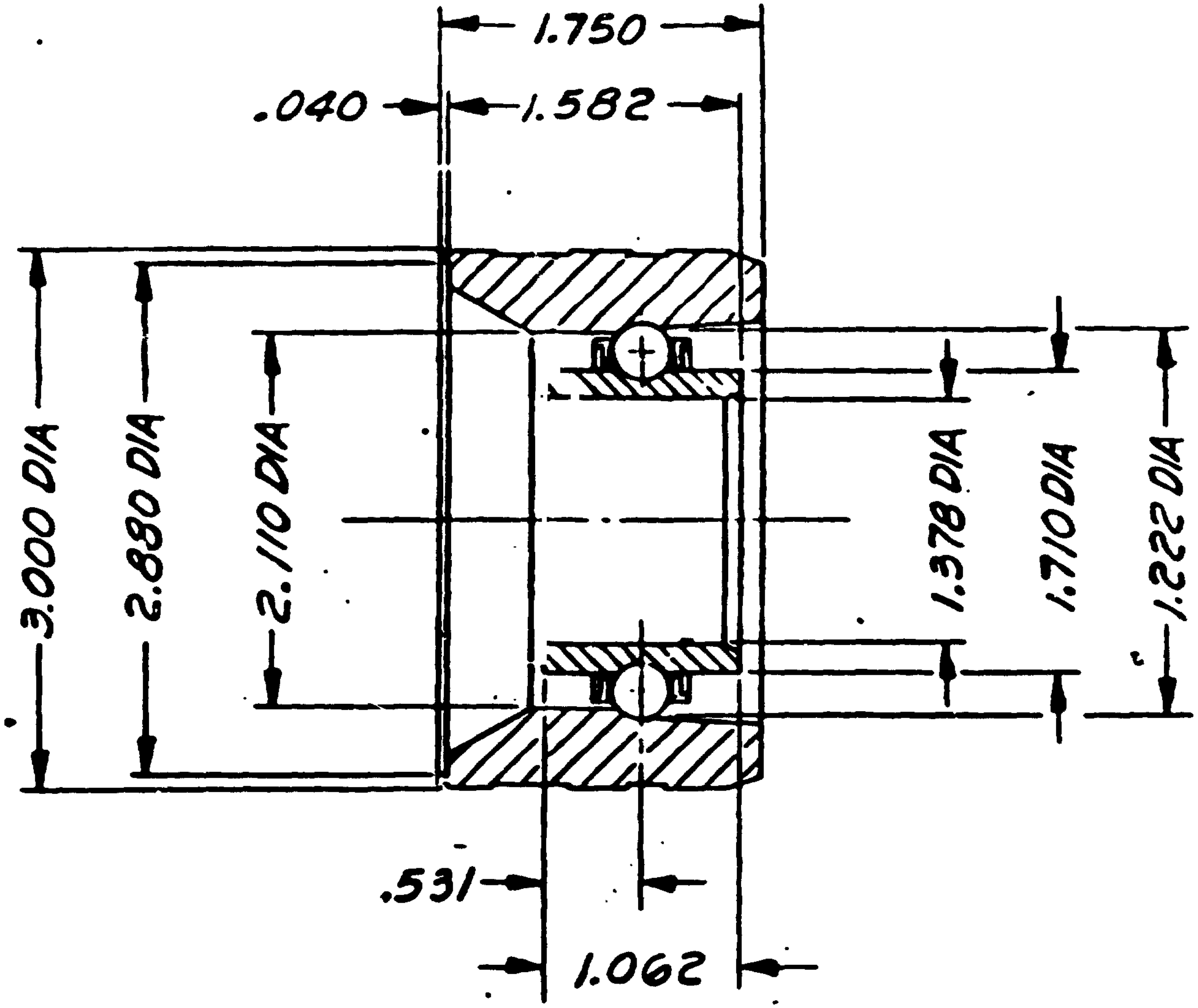
Lubricant Film Thickness vs Speed and Temperature Condition
107H Bearing - KG-80 Oil

Speed RPM	Temp ^{o}F	Film Thickness Inner Race Micro Inches	Film Thickness Outer Race Micro Inches
8000	110	52	56
	140	30	34
	180	18	21
9100	100	55	61
	140	32	36
	180	19	22

The ATM/CMG bearing assembly is shown in Figure 1.4.1.2-5 with the basic sizes shown in Figure 1.4.1.2-6. The bearing is basically a standard 107H type but the outer



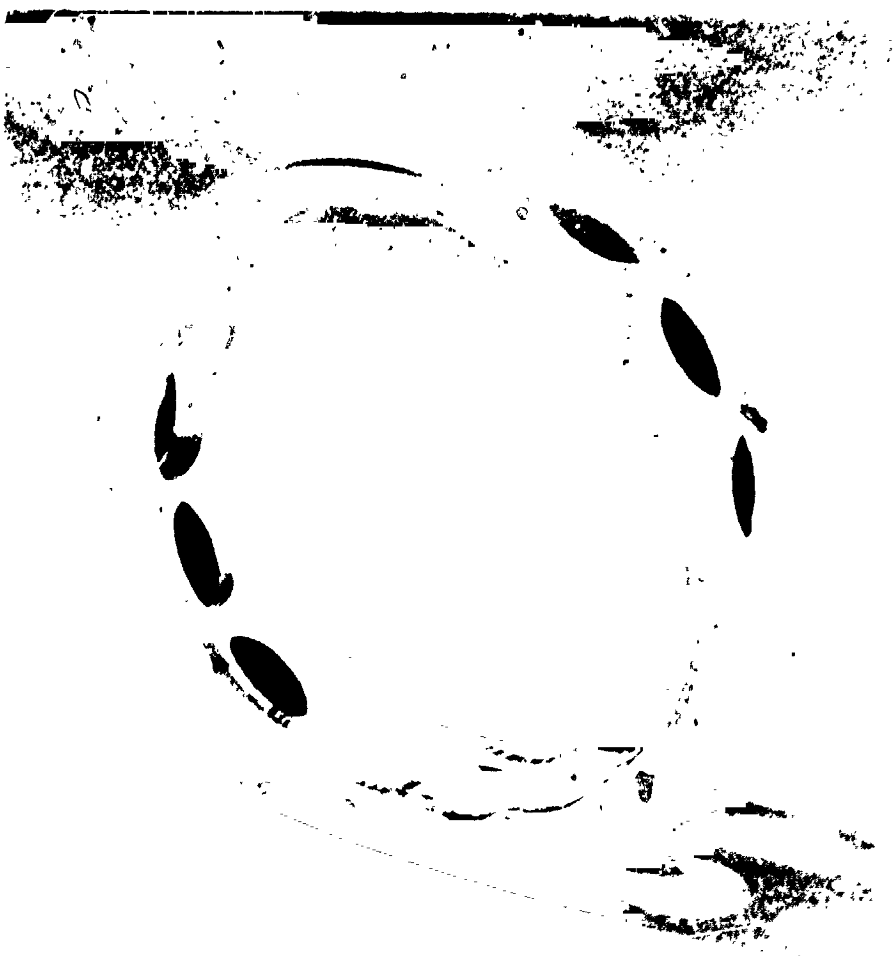
BEARING ASSEMBLY
FIGURE 1.4.1.2-5



ATM-CMG SPIN AXIS BEARING

FIGURE 1.4.1.2-6

NOTES



RETAINER
FIGURE 1.4.1.2-7

race is a special design that allows a sliding interface of the bearing to the bearing cartridge; thus, it is termed an integral slider bearing. The bearing retainer configuration has been designed to receive the oil from the lubrication nut and transfer lubricant to the area of the balls and races. The retainer, Figure 1.4.1.2-7, is inner race riding and has been modified to accept a larger volume of oil without retainer instability. The bearing is received disassembled and is assembled and tested at Bendix. The bearing has the following specifications and capabilities.

BEARING PARAMETERS

Bearing type	Angular contact 107H (relieved outer race)
Bearing size	3.000 in. O.D., 1.3780 in. bore
Materials	Races and balls 52100 CEVM steel Retainer - cotton base phenolic Grade L
Quality	ABEC 9 or better
Ball compliment	15, .3125 dia.
Nominal contact angle	$15^{o} \pm 2^{o}$ with 10# thrust load
Inner race curvature	51.6% of ball dia.
Outer race curvature	53.0% of ball dia.
Lubricant	Kendall KG-80
Manufacturers	The Barden Corp. SBB Div. MPB Corp.
Special procedures	TCP soak Smoothrator test Wettability test Retainer stability

BEARING CAPABILITIES

Static thrust capacity	2900 lbs
Static radial capacity	2500 lbs
Basic dynamic load rating	3510 lbs
Dynamic capacity 8000 rpm	567 lbs
Dynamic capacity 9100 rpm	531 lbs
L10 life under duty cycle	122,000 hrs
Cumulative life test hrs	In excess of 400,000 hours

The unit described has passed qualification tests in both thermal vacuum and vibration. In both cases the system performed in excess of requirements.

A summary of physical characteristics and performance results accumulated on the IGRA is presented in the following tabulations.

PERFORMANCE CHARACTERISTICS OF THE IGRA

Maximum output torque capability	160 ft-lbs
Momentum storage	2300 ft-lbs-sec
Wheel operating speed	9000 rpm
Wheel acceleration time (with inverter)	14 hours maximum
Power at run speed	30 watts nominal at 5 microns
Maximum power on run up	175 watts
Wheel deceleration time	Coast: hrs 35 $\pm$10 DC brake: hrs 5$\pm$1 at 2.5 amps
Life (under AMT torquing duty cycle)	10,000 hours (min)
Life (under zero "g" no torque duty cycle)	20,000 hours (min)
Maximum gimbal rate capability	4.0 deg per second

ROTOR AND INNER GIMBAL ASSEMBLY

PHYSICAL CHARACTERISTICS

Rotor material	steel
Rotor diameter	22"
Rotor weight	145 lbs
Speed	7850 rpm (for 2000 ft-lb-sec angular momentum)
Rotor inertia	$2.43 \pm .02$ ft-lbs-sec^2
Rotor stress safety factor	5.0
Rotor speed safety factor	2.25
Maximum dynamic unbalance	less than 50 microinch
Inner gimbal assembly weight	235 lbs
Inner gimbal internal free volume	1.3 cu ft
Total inner gimbal volume	2.0 cu ft
Rated torque capability	200 ft-lb
Operating life	10,000 hours minimum (under torquing duty cycle)
Operating life	20,000 hours minimum (under zero "g" torque duty cycle)
Storage life	5 years
Run up time	8-12 hours (without inverter)
Maximum Bearing Operating Ambient Temp	180°F
Motor Supply	115V 400 cps 3 phase (for 2000 ft-lb-sec)

ROTOR AND INNER GIMBAL ASSEMBLY
PERFORMANCE TEST RESULTS

Starting power	170 watts
Running power horizontal (5 micron pressure)	30 watts
Running power vertical (5 micron pressure)	50 watts
Bearing power (horizontal)	18 watts (nominal)
(Horizontal 76°F sink)	86°F
Bearing vibration output (filtered)	0.5 g RMS
Maximum rate applied	11°/sec
Windage power (approximate)	
1000 micron pressure	50-60 watts
100 micron pressure	25-30 watts
10 micron pressure	10-15 watts
1 micron pressure	2 watts
Total power at 1000 microns - approximately	75 watts

<u>Acceleration and Deceleration Data</u>

Run up time at room temperature	8 hours
Run up energy	1.1 KWH
Run down time (normal)	34 hours
Run down time (DC brake at 2.5a)	4.5 hours
Run down time	
(1 ATM N_2 DC at low speed)	40 min

1.4.1.3 Actuator Pivot Assemblies

1.4.1.3.1 General Description and Characteristics

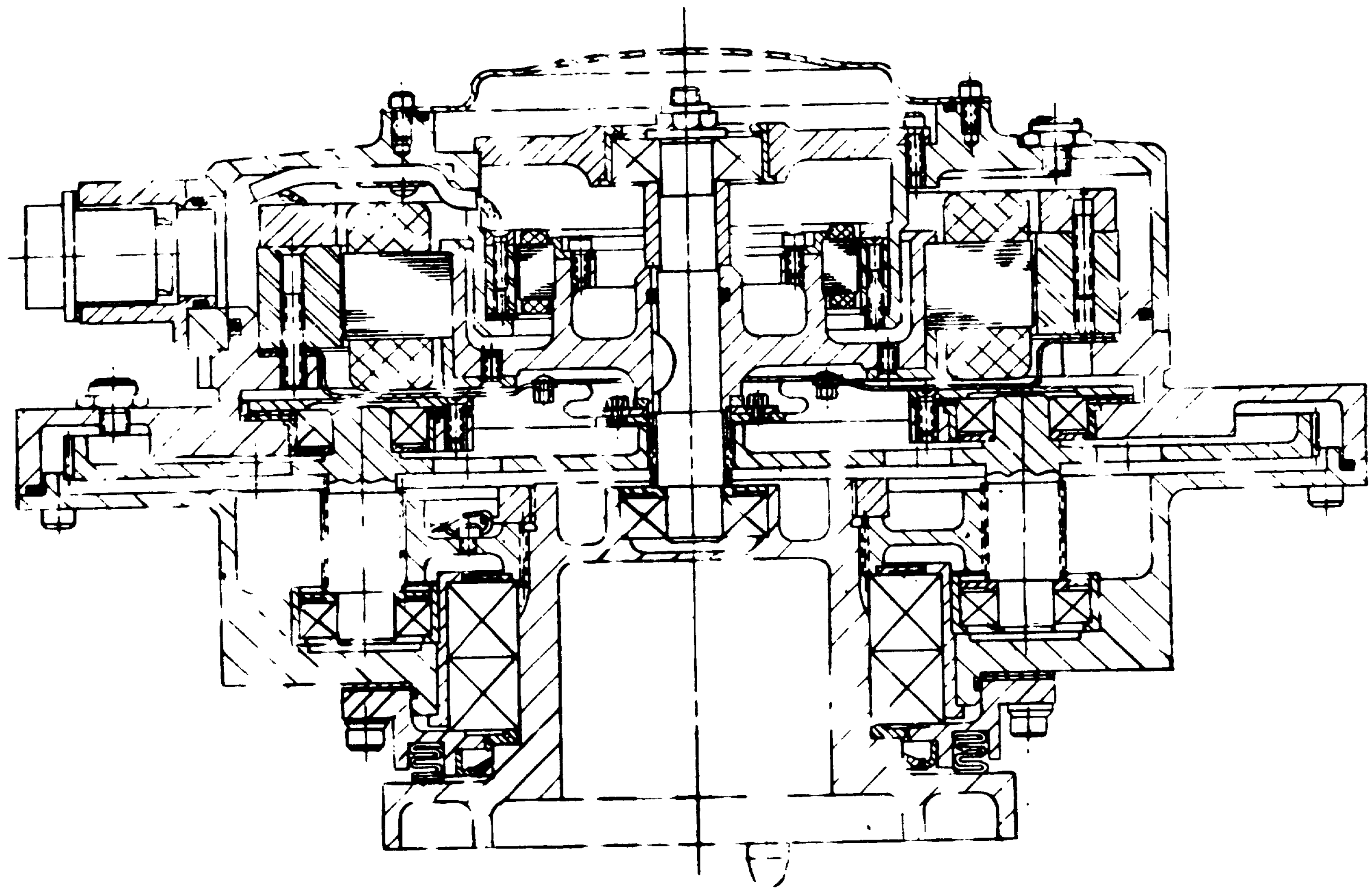
The CMG actuators provide the rotational torque to the gimbal assemblies and, with the sensors, serve as the gimbal pivots.

The inner and outer actuators of the ATM CMG are identical except for their external finish. For thermal considerations the inner actuator is finished with CAT-A-LAC Flat Black Paint No. 463-3-8, an epoxy base material. To conform with the MSFC requirement that external surfaces of the CMG have low solar absorbtance and high emittance characteristics, the outer actuator is finished with Pyromark White Paint.

The actuator, shown in Figure 1.4.1.3-1 and described in detail in the following paragraphs, consists basically of a housing assembly, gear train, torque motor and tachometer. The gear train is a two stage, parallel path, reverted spur gear system, with the required zero backlash feature provided by winding up the gear train so that one path is preloaded against the other.

All materials in the actuator, including lubricants, insulation, adhesives, encapsulants, elastomers and finishes, conform with NASA document 50M02442, "ATM Material Control for Contamination due to Outgassing".

The actuator characteristics are tabulated in Figure 1.4.1.3-2.



ACTUATOR LAYOUT
FIGURE 1.4.1.3-1

The unit is shown in photographs Figure 1.4.1.3-3 and 1.4.1.3-4.

1.4.1.3.2 Gear Train and Bearings

In actuator life tests conducted early in the ATM CMG program, while the mission life was only 56 days and the unit was dry film lubricated, a gear wear problem became evident. At MSFC direction, Bendix contracted with Battelle Memorial Institute to perform a review of the Bendix design. They were also to optimize the gear train design for maximum wear life and maximum actuator spring rate, while taking into consideration the status of the hardware and the program schedule.

ACTUATOR CHARACTERISTICS

Output torque - rated max	122 ft lb
Output speed - rated max	3.5 degrees/sec
Torquer to output ratio	56.55:1
Backlash	zero
Torsional spring rate	35,500 ft lb/radian
Torque sensitivity (torquer)	1.15 ft lb/amp
Tachometer scale factor	1.0 volts/rad/sec
Weight	23 lbs

Figure 1.4.1.3-2

As part of their review, Battelle took a broad look at the two stage, parallel path, preloaded gear train and compared it to possible alternative systems and types of gearing that could provide the required

ACTUATOR PIVOT ASSEMBLY
FIGURE 1.4.1.3-3

performance with high torsional stiffness and zero backlash. Systems that were considered included traction drives, harmonic drives, epicyclic gear systems and the use of helical or herringbone gears. Their study confirmed that the basic configuration of the actuator and its gear train provided the best means of meeting the specified requirements.

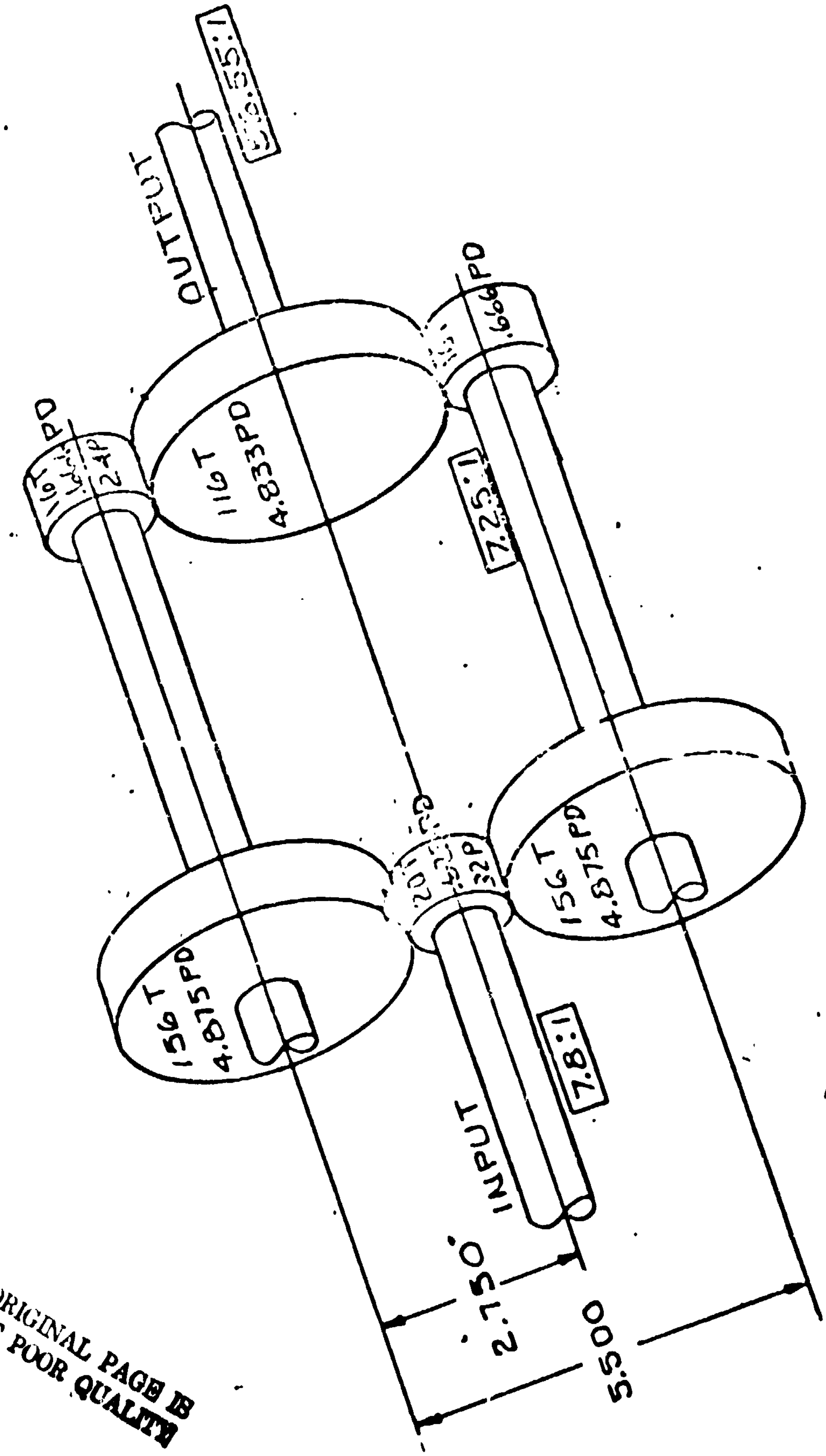
In their review of the gear train details, Battelle's general approach was to optimize against the predominant wear mode of failure by using techniques that improved the load sharing between the two paths. This improvement could be achieved by reducing the clearances existing in the unpreloaded gear train and by keeping to a minimum the preloading torque required to "wind up" the gear train sufficiently to maintain a zero backlash under all operating conditions. The resulting improvements in load sharing would minimize the loading on the gear teeth and shaft bearings.

Battelle's studies are documented in their Design Review of CMG Actuator", dated July 31, 1970, copies of which have been delivered to MSFC. Wherever possible, their recommendations were incorporated into a modified design that became the flight configuration.

The actuator gearing schematic is shown in Figure 1.4.1.3-5. The basic gearing data is tabulated in Figure 1.4.1.3-6 and the detailed gear engineering data in Figure 1.4.1.3-7. Gear ratios, diametral pitches, modified gear tooth profiles and face widths were selected so that the resulting sliding velocities and Hertzian contact stresses were conducive to maximum wear life. Gears and shafts utilized to the greatest possible extent, short, large diameter configurations, to minimize torsional deflections, tooth bending and shaft bending, the major contributors to actuator compliance.

The number of teeth in the gear train were selected to provide the smallest preloading increment (the angle that the input pinion must rotate to achieve a wind up of one tooth mesh). In the original design, this increment had been 4.5 degrees. In the flight version it was reduced to 0.9 degrees. Keeping this increment small is an important factor in reducing the preload torque and improving load sharing between the two gear paths.

All gears were fabricated of nitralloy, core hardened



GEAR SCHEMATIC

FIGURE 1.4.1.3-5

	Input Drive Gear Ratio R_i = 7.8		Output Drive Gear Ratio R_o = 7.25	
	Pinion	Gear	Pinion	Gear
Number of teeth	25	195	16	116
Diametral pitch	40	40	24	24
Standard pitch diameter, in.	0.6250	4.8750	0.6667	4.8333
Tooth form	Long Add	Short Add	Long Add	Short Add
Addendum modification, in.	+0.006	-0.006	+0.014	-0.014
Face width (nominal), in.	0.656	0.372	0.835	0.718

a. The basic tooth profile is a 20-degree full-depth involute for all gears.

b. All gears are made of Nitralloy bar, MIL-S-23966, Class A, Condition 2. They are heat treated to a core hardness of R_c = 34 to 38 and nitrided to case hardness of R_c = 65 to 67 with a somewhat varying case depth (in the 0.006 to 0.0014 inch range).

BASIC GEAR DATA

FIGURE 1.4.1.3-6

SPUR GEAR DATA

	Input Drive		Output Drive	
	Pinion	Gear	Pinion	Gear
Number of teeth	25	195	16	116
Diametral pitch	40	40	24	24
Pressure angle	20^{o}	20^{o}	20^{o}	20^{o}
Standard pitch diameter (N/P)	.625	4.875	.66667	4.83333
Base circle diameter (REF)	.58731	4.58100	.62646	4.54185
Tooth form	Long add	Short add	Long add	Short add
Addendum modification (REF)	+.006	-.006	+.014	-.014
Maximum addendum (REF)	.0310	.0190	.0557	.0277
Minimum whole dpeth (REF)	.0570	.0570	.0937	.0937
Maximum calculated circular tooth thickness on standard pitch circle (REF)	.04365	.03398	.07565	.05474
Measuring pin diameter	.0432	.0432	.072	.072
Measurement over two pins	.6936-.0007	4.9219-.0010	.7867-.0007	4.9066-.0010
Max total composite error (TCE)	.0004	.0004	.0004	.0004
Max tooth-to-tooth composite error (TTCE)	.0003	.0003	.0003	.0003
Outside diameter	.6870-.0010	4.9130-.0010	.7780-.0015	4.8887-.0015
Outside diameter runout MAX TIR	.0010	.0010	.0010	.0010
Root diameter	.5730-.0070	4.7990-.0070	.5906-.0200	4.7013-0.100
Minimum root fillet radius	.0070	.0070	.0110	.0110
Form diameter, MAX	.5920	4.8200	.6280	4.7500

FIGURE 1.4.1.3-7

to R_c 34/38 and nitrided to a case hardness of R_c 65/67. After nitriding, all gears were finish ground and lapped, insuring that optimum concentricities and tooth accuracies were obtained.

The pivot bearings are a preloaded duplex pair, mounted "back-to-back" for maximum shaft rigidity under moment loads. The load capacity of the pivot bearings is adequate to withstand launch vibration loads.

The gear train bearings are all angular contact bearings, purchased to ABEC-7 quality and, at assembly, are shimmed to remove axial clearance.

1.4.1.3.3 Housings and Shafts

The actuator housing assembly is made of four individual housings, hogged out of AZ31B magnesium tooling plate, with hardened steel liners shrunk in place for all ball bearing bores. During the machining process, all parts were subjected to stress relieving and stabilizing operations and were inspected with both radiographic and fluorescent penetrant methods. All tapped holes in the housings were fitted with self-locking inserts, to furnish maximum strength and secure fastening for screws. After the individual housings were semi-finished and dowelled to each other, the ball bearing bores and the torquer and tachometer mounting diameters were finish machined to close dimensional and concentricity tolerances. The housings were then finished with an electrically conductive iridite coating and their external surfaces painted. The finished housing assembly is maintained as a matched set.

The actuator output shaft, which acts as the gimbal pivot shaft, was machined from forged 6AL-4V titanium alloy. The shafts were stress relieved after rough machining and stabilized prior to the final grinding operation. A conversion coating of "Hi-Shear", a proprietary finish process, was applied to the finished parts, providing anti-galling properties to prevent the mating ball bearings and retaining nuts from seizing on the titanium.

1.4.1.3.4 Torque Motor and Tachometer

Inland Motor Corp. T-5793A, a 7.0 ft lb DC permanent magnet torque motor and TG-2815A tachometer generator were selected for the actuator. Characteristics of the motor are tabulated in Figure 1.4.1.3-8 and the tachometer in Figure 1.4.1.3-9. Both motor and tachometer are rated for a maximum temperature of $155^{\circ}C$.

The torque motor uses brushes fabricated of Boeing compound 046-45 (a proprietary material composed of tantalum and molybdenum disulfide) and a gold plated commutator. This brush material was recommended by the Materials Division at MSFC on the basis of its low wear rate in vacuum operation. MSFC testing indicated a wear rate of 0.5 inch for 10^{10} inches of travel, providing a high confidence level for long life operation.

The same material had originally been specified for the tachometer brushes. However, extensive investigation of an electrical noise problem that arose during thermal vacuum testing, demonstrated that brushes composed of 50% silver - 50% graphite effectively eliminated the electrical noise without introducing a wear problem.

Torque Motor Characteristics

Inland Part No.	T-5793A
Brush Material	Boeing 046-45
DC Resistance	6.9 $\pm$12.5% ohms
Torque sensitivity	1.15 $\pm$10% ft lb/amp
Back EMF	1.53 $\pm$10% volts/rad/sec
Inductance	.021 henries
Peak torque	7.0 ft lb
Elect time constant	.0027 sec
Mech time constant	.02 sec
Power at peak torque	225 watts
Ripple torque	4%
Ripple cycles per revolution	79
Max temp rating	155°C

Figure 1.4.1.3-8

Tachometer Characteristics

Inland part no.	TG-2815A
Brush material	50% silver - 50% graphite
DC resistance	273 $\pm$12.5% ohms
Voltage sensitivity	1.0 $\pm$.1 volts/rad/sec
Inductance	.28 henries, max
Ripple voltage	4%
Ripple cycles per revolution	71
Max temp rating	155^{o}C

Figure 1.4.1.3-9

1.4.1.3.5 Lubrication, Seals and Vents

When the ATM mission life was extended from 56 days to 300 days, gear and bearing wear life considerations made it necessary to change the lubrication system from dry film to oil and grease lubricants. After consultations with the Materials Division of MSFC and lubrication specialists at Battelle Memorial Institute, the type of lubricants selected for use in the actuator were a perfluorinated ether oil and a grease made of the same oil thickened with Vydax, a fluorocarbon telomer suspended in Freon TF.

As part of their "Design Review of a CMG A tuator", Battelle evaluated two greases of this type - Du Pont Krytox 240 AC and Bray Oil Co. Braycote 3G503, both of which had excellent boundary lubricating properties and low vapor pressures.

Results of outgassing and weight loss measurement tests demonstrated that the Krytox grease was not acceptable for this application. The Bray grease, however, proved far superior in this area and was qualified as a material meeting the requirements of NASA document 50M02442, "ATM Material Control for Contamination due to Outgassing". Acceptance of the lubricant as a material, meant that the effectiveness of the actuator seals and vents in preventing contamination of the vehicle optics by escaping lubricant vapor, was irrelevant.

Due to quality control problems that were uncovered at Bray Oil Co., the lubricants were qualified on a batch basis. Bendix purchased from Bray, quantities of oil and grease in excess of total program needs. At Bendix, the grease was homogenized in a three roll mill, and both oil and grease were subjected to a vacuum bake out process, established by Battelle, that released undesirable light fractions of the oil. Lubricants from this particular batch, processed in this manner, qualified as acceptable materials.

The qualified Bray oil and grease were used in the flight configuration of the actuator. Ball bearings and gears were lubricated with the grease and the ball bearing phenolic retainers were vacuum impregnated with the oil.

Battelles' tasks also included investigations of lubrication distribution techniques. Their observations of grease films remainining on the teeth of test gears that had been subjected to a number of meshing cycles equivalent to 10 months of duty cycle operation, indicated that for the ATM mission the actuator did not require lubricant reservoirs or grease wipers. The redistribution mechanisms inherent in meshing gear teeth were adequate for the required 10 month lifetime.

A detailed account of Battelle's studies and tests relating to the subject of actuator lubrication is included in their "Design Review of a CMG Actuator".

During investigation of the tachometer brush noise problem, it was observed that some of the lubricant from the gear train had contaminated the tachometer commutator and might have contributed to the problem. To prevent this lubricant migration, a face seal, spring loaded by a bellows, was incorporated and effectively isolated the motor and tachometer section from the gear train.

Parting surfaces of the housings were provided with "O" ring seals fabricated of Viton A. A lip seal between the stationary housing and the rotating shaft excluded contamination from the output end of the unit.

A grounding bellows of gold plated, electrodeposited nickel provided an electrical bond between the output shaft and housing for EMI control as well as affording an additional face seal at the rotating shaft. Further attenuation of conducted and radiated EMI was obtained by using Bendix connectors with built in filters on each contact pin.

Each actuator was provided with two housing vents - one for the gear train section and one for the motor and tachometer section. These vents, with 2 micron filter screens, permit viscous flow, so that during launch or initial test pump down, no severe pressure differential will exist between the pivots and their environment. The resistance of these devices to molecular flow will restrict the loss of lubricant by evaporation while in a vacuum environment.

1.4.1.4 Sensor Pivot Assemblies

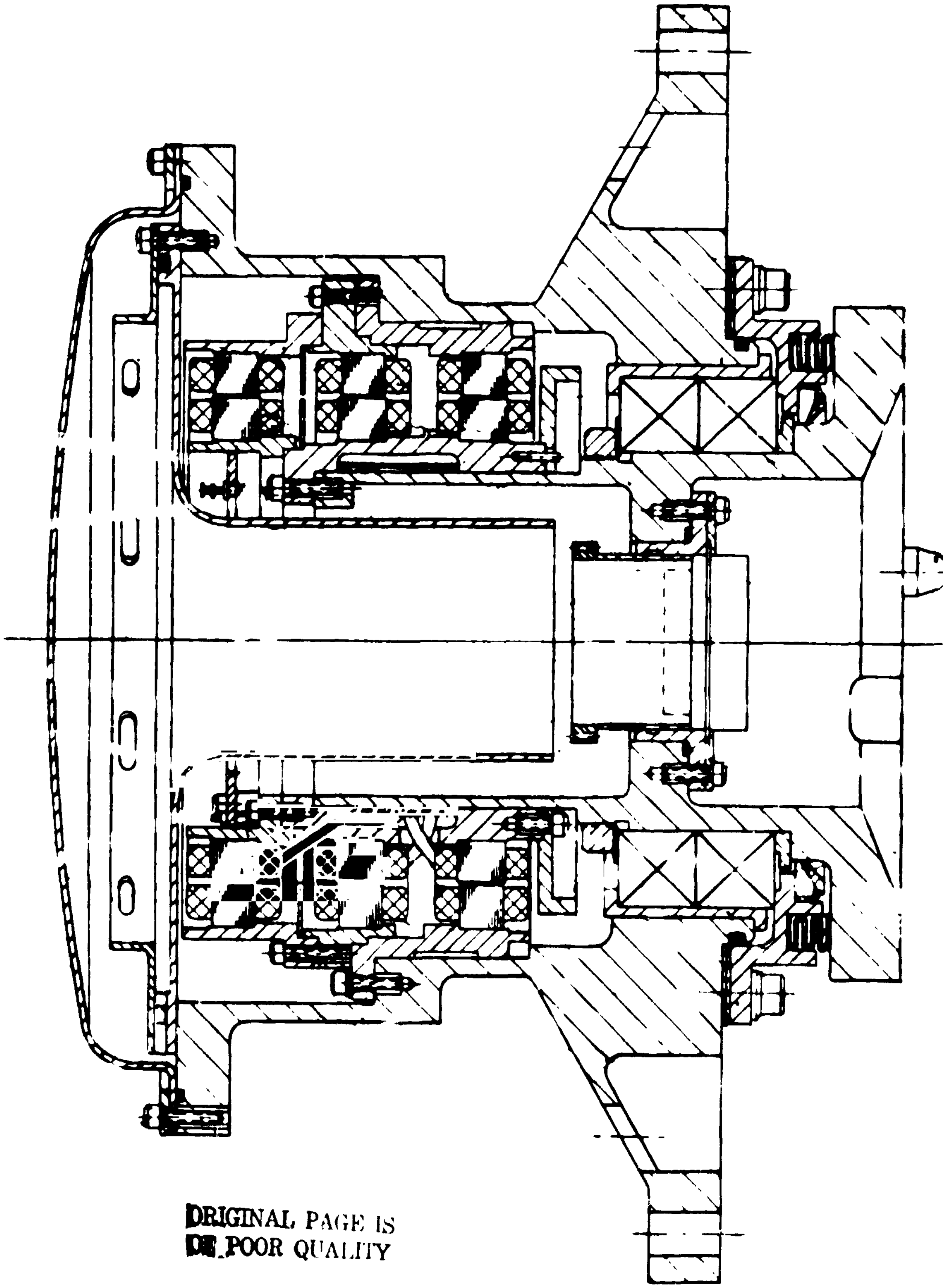
1.4.1.4.1 General Description

The sensor pivots provide for the transmission of electrical power and signals across the gimbals and, with the actuators, serve as gimbal pivots.

The sensor pivot, shown in Figure 1.4.1.4-1, consists of a housing, a ball bearing mounted pivot shaft, a resolver assembly, cam operated limit switches and a flex lead assembly.

With the exception of the sensor housings, the wiring, the shaft travel and the external finish, the inner and outer sensors are essentially the same.

To achieve outer gimbal balance, it was necessary to add weight to the inner sensor to counter the heavier actuator assembly. This was accomplished by fabricating the inner sensor housing of aluminum alloy 2024T4. For the outer sensor, where no balance problem existed, the housing was machined from AZ31B magnesium tooling plate.



SENSOR LAYOUT
FIGURE 1.4.1.4-1

As with the actuators, discussed in paragraph 1.4.1.3.1, the inner sensor is finished with CAT-A-LAC Flat Black Paint No. 463-3-8 and the outer sensor with Pyromark White Paint.

All materials used in the sensors also conform with NASA document 50M02442, "ATM Material Control for Contamination Due to Outgassing".

The physical and performance characteristics of the sensors are tabulated in Figure 1.4.1.4-2.

PHYSICAL AND PERFORMANCE CHARACTERISTICS
OF THE SENSOR PIVOT ASSEMBLIES

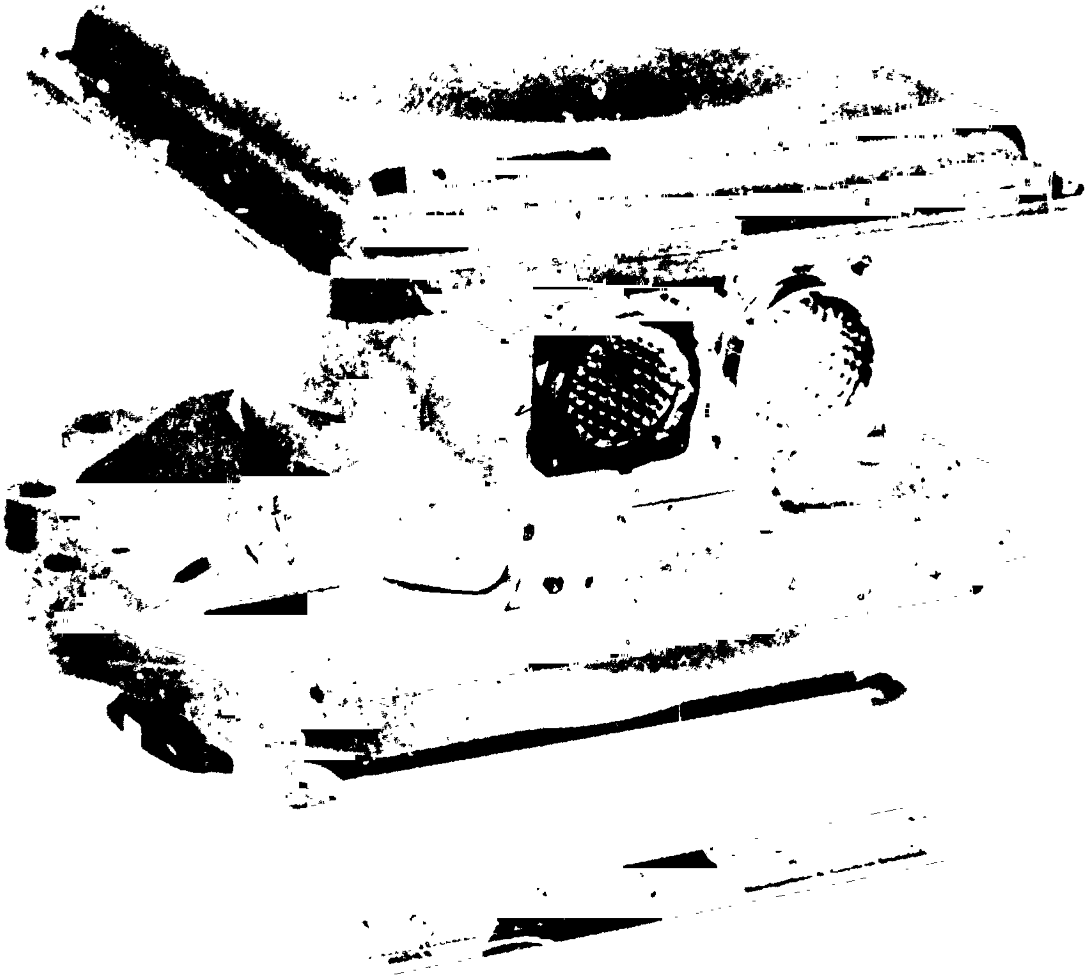
	Outer Gimbal	Inner Gimbal
Weight	16.3 lbs.	20.0 lbs.
Wiring	73 flex leads	29 flex leads
Limit Switch Setting	$+215^{\circ}$ and -125°	$\pm 75^{\circ}$
Mechanical Rotation Limit	$+220^{\circ}$ and -130°	$\pm 80^{\circ}$
Linear Resolver		
Primary Winding	rotor	rotor
Primary Voltage	10 volts rms	10 volts rms
Primary Frequency	4800 Hz	4800 Hz
Number of Poles	2	2
Voltage Ratio	0.500 to 1	0.500 to 1
Sensitivity	55 mv/deg	55 mv/deg
Error	$\pm 4.0^{\circ}$	$\pm 4.0^{\circ}$
Null (sine winding)	50 mv	30 mv
Outputs	0 to 9.5 volts for $+45^{\circ}$ to -130° and $+45^{\circ}$ to $+220^{\circ}$ (null at $+45^{\circ}$)	0 to 4.4 volts rms for 0° to $\pm 80^{\circ}$ (null at 0°)

Figure 1.4.1.4-2 (Sheet 1)

Desaturation Resolver	Outer Gimbal	Inner Gimbal
Primary Winding	rotor	rotor
Primary Voltage	cosine output of I.G. Desaturation Resolver	10 volts rms
Primary Frequency	4800 Hz	4800 Hz
Number of Poles	2	2
Voltage Ratio (no load)	1.06 to 1	1.06 to 1
Error (max)	$\pm 500 \times 10^{-3}$ deg (± 30 minutes)	$\pm 500 \times 10^{-3}$ deg (± 30 minutes)
Null	30 mv at 0°	30 mv at 0°
Output	sine cosine output	sine output cosine output excites O.G. desaturation resolver

Control Law Resolver		
Primary Winding	stator	stator
Primary Voltage	10 volt rms	10 volt rms
Primary Frequency	4800 Hz	4800 Hz
Number of Poles	2	2
Voltage Ratio	0.82 to 1	1.03 to 1
Error (max)	$\pm 500 \times 10^{-3}$deg (± 30 min)	$\pm 167 \times 10^{-3}$deg (± 10 min)
Null	50 mv	50 mv

Figure 1.4.1.4-2 (Sheet 2)



SENSOR PIVOT ASSEMBLY
FIGURE 1.4.1.4-4

68-3360

The unit is shown in photographs, Figures 1.4.1.4-3 and 1.4.1.4-4.

1.4.1.4.2 Flex Lead Assembly

As maximum pivot shaft rotation is limited to $\pm 175^{\circ}$, power and signal circuits are conducted across the pivots by a flex lead assembly. Avoiding the use of a slip ring assembly eliminates concern for the wear life of sliding contacts.

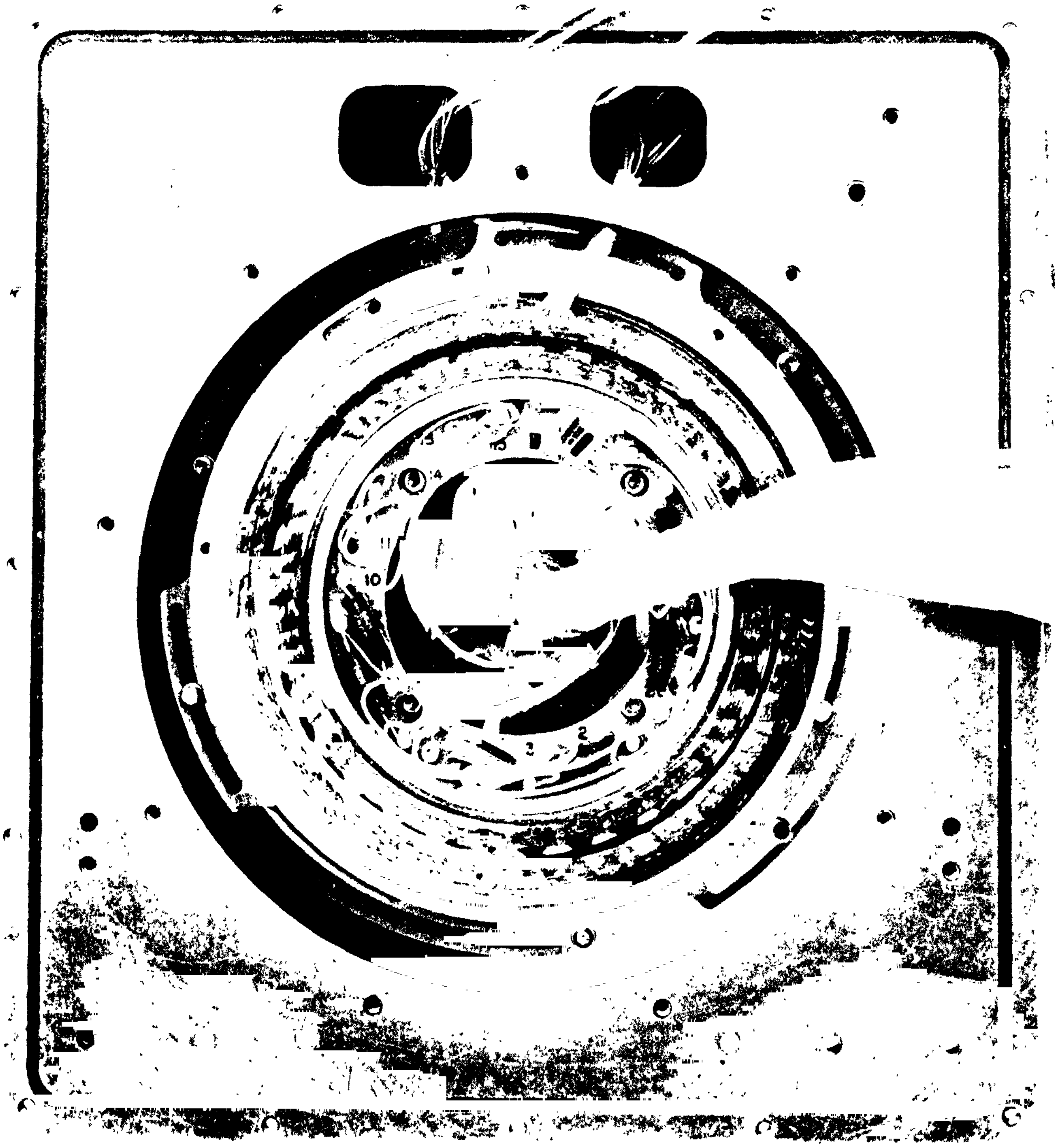
Leads of this assembly are terminated at the center electrical connector that rotates with the pivot shaft, and are mechanically supported by the connector potting. The leads are then dressed through a shaped nylon guide to their stationary termination points. Figures 1.4.1.4-5 and 1.4.1.4-6 show views of the flex leads during the assembly process.

Life tests at room environment and at low temperature had been successfully performed on the flex lead assembly early in the sensor program. These tests are described in MT 15,111, Issue A, dated October 16,1968, copies of which have been transmitted to MSFC.

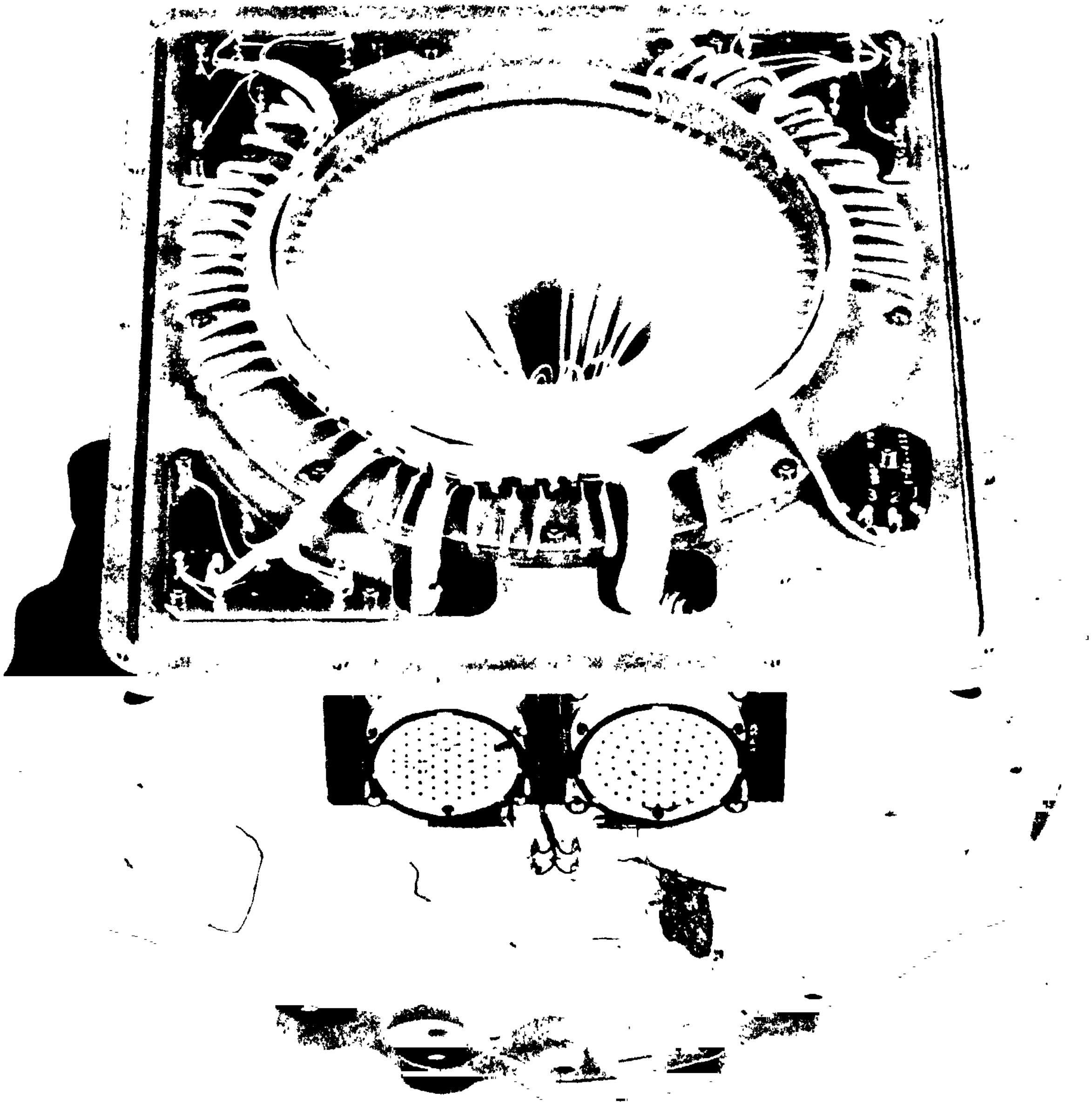
1.4.1.4.3 Resolver Assembly

Each sensor pivot incorporates three pancake resolvers for computation and readout.

a. The first resolver, designated the Control Law Resolver, is employed in a resolver chain adjusting gimbal commands as a function of gimbal angle.



FLEX LEAD VIEW
FIGURE 1.4.1.4-5



FLEX LEAD VIEW
FIGURE 1.4.1.4-6

b. The second resolver, called the Linear Resolver, provides an output signal linear with gimbal angle for telemetry after conditioning in the inverter assembly.

c. The third resolver, called the Desaturation Resolver or "H" Feedback Resolver, is employed in a resolver chain for reading out the CMGs momentum vector components relative to the CMG base.

Characteristics of the resolvers are included in Figure 1.4.1.4-2.

At final sensor assembly the resolver assembly is accurately adjusted to the null position while the zero angle relationship between the pivot shaft and the housing is held by fixturing.

1.4.1.4.4 Limit Switches

Hermetically sealed microswitches, operated by cams that are keyed to the pivot shaft, indicate when each gimbal is within 5 degrees ofits mechanical stop. With the inner gimbal mechanically limited to $\pm 80^{\circ}$, the inner sensor switches operate at $\pm 75^{\circ}$ of shaft travel. For the outer gimbal travel of $+220^{\circ}$ and -130°F. The outer sensor switches function at $+215^{\circ}$ and -125°.

The cam followers are fabricated from Du Pont Vespel SP31, a molybdenum disulfide filled polyimide with self lubricating properties.

At final assembly, with the angular relationship between the pivot shaft and the housing maintained by fixture and an index head, the switches are closely adjusted to operate at the required angles.

1.4.1.4.5 Mechanical Design Details

As mentioned in the general description, the inner sensor housing is machined from 2024T4 aluminum alloy and the outer sensor housing from AZ31B magnesium. Both housings have hardened steel liners shrunk in place for the pivot bearing bores. During the machining process all housings were stress relived and stabilized and inspected by radiographic and fluorescent penetrant methods. All tapped holes were fitted with self-locking inserts. Finished housings had an electrically conductive iridite coating applied prior to painting of their external surfaces.

As with the actuator, the pivot shafts were machined from 6AL-4V titanium forgings, with an anti-galling coating of "Hi-Shear" applied to the finished parts.

The pivot shaft is supported in the sensor housing by the same stainless steel, preloaded, duplex ball bearing pair used in the actuator. The pivot bearings use the same lubricants described in the actuator section, paragraph 1.4.1.3.5.

The sensor also uses the same approach to sealing and venting as the actuator, using parts common to both units for the shaft lip seal, the grounding bellows and the housing vent.

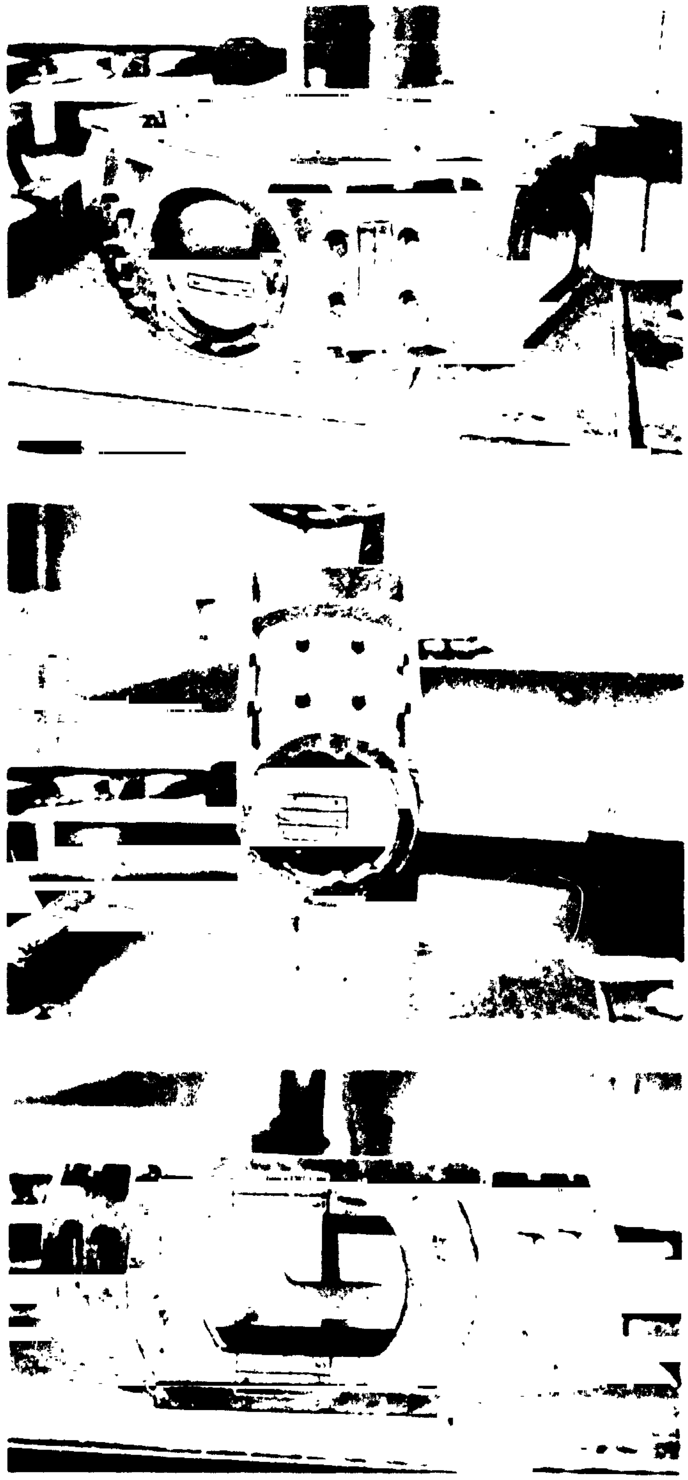
1.4.1.5 Outer Gimbal

The outer gimbal provides pads to interface mechanically with the shafts of the outer actuator and sensor pivots by which it is supported. It also provides surfaces for the mounting of the inner pivot housings, establishing the axis of rotation of the inner gimbal assembly, which it supports, in the same plane and perpendicular to the axis of outer gimbal rotation.

The basic outer gimbal is a thin walled sand casting of QE22A, Temp T6, magnesium alloy. After the raw casting was thoroughly inspected by radiographic and fluorescent penetrant methods, it was rough machined and .125 thick magnesium stiffening plates were welded on as an outer skin. After welding, the assembly was stress relieved and the fluorescent penetrant inspection was repeated. The gimbal was then finish machined, maintaining close tolerances on the required parallelism and perpendicularity relationships of the pivot mounting surfaces. Stress relieving and stabilization procedures were performed at appropriate stages of the machining sequence and the gimbal was again fluorescent penetrant inspected. All tapped holes were fitted with self locking inserts. The finished part was coated with Iridite 15 and painted with CAT-A-LAC 463-3-8 flat black epoxy paint.

Weight of the finished outer gimbal was 26.5 lbs.

The raw gimbal casting is shown in photograph Figure 1.4.1.5-1 and the finished gimbal in Figure 1.4.1.5-2.



RAW GIMBAL CASTING
FIGURE 1.4.1.5-1

GIMBAL, OUTER P/N 712066
FIGURE 1.1.1.-2

1.4.1.6 Frame

The CMG frame provides the mechanical interface with the ATM rack, supports the outer gimbal assembly and includes provisions for mounting the CMG Electronics Assembly, the elapsed time indicator and the outer gimbal stop bracket.

The mechanical interface is provided by accurately sized and located holes in the frame mounting feet. Each of the four mounting feet has one hole for a shoulder bolt and two holes for locating dowel pins in the rack.

The basic frame is a sand casting of QE22A, Temp T6 magnesium, with a ribbed, thin walled configuration designed to achieve light weight and the required rigidity. Prior to machining, the raw casting was thoroughly inspected by radiographic and fluorescent penetrant methods. At appropriate stages of the machining sequence, stress relieving and stabilization operations were performed, to eliminate any latent residual stresses that might have caused distortion. Heat treated, corrosion resistant steel bushings were installed for all mounting holes, caging pin holes and pivot locating dowels. All tapped holes were fitted with self-locking inserts.

In the finish machining operation, the four mounting feet were finished flat and in the same plane and the mounting holes through the steel bushings were finish bored to the required spacing and tolerances. In order to accurately establish the outer gimbal axis of rotation, close tolerances were also held in finishing the pivot mounting pads parallel to each other and perpendicular to the plane of the mounting feet.

The finished frame was coated with electrically conductive Iridite 15 and, except for the component mounting surfaces, was painted with Pyromark White paint.

Weight of the finished frame was 33.0 lbs.

A photograph of the semi-finished frame is shown in Figure 1.4.1.6-1. Views of the finished frame can be seen in photographs of the overall CMG, Figures 1.4.1.1-1 and 1.4.1.1-2.

1.4.1.7 Frame Covers

Covers that fasten to the frame and completely enclose the rotating gimbals were included in the CMG configuration, with the prime purpose of providing protection to the astronauts during EVA maneuvers. As secondary functions, the covers also acted as additional thermal dampers for the spin bearings and increased the stiffness of the frame.

Each of the top and bottom cover assemblies (Bendix P/N 2120552-9 and -10) consists basically of a deep drawn shell of .040 thick aluminum alloy 6061, heat treated and age hardened to T6. A .125 thick stiffening ring of the same alloy is permanently joined to the cover flange with a series of spot welds and

SEMI FINISHED FRAME
FIGURE 1.4.1.6-1

the entire cover periphery.

All screws that fasten the cover to the frame are captivated in threaded bushings that are flared into countersunk holes in the cover flange.

After the cover is treated all over with Iridite 14-2, all inside surfaces are finished with CAT-A-LAC Flat Black paint and all outside surfaces with Pyromark White paint.

The top cover is provided with a removable access door, assembled to the cover with captivated screws. This door is fitted with a screened vent that prevents the existence of a pressure differential across the covers. The door can be removed to provide access to the evacuation valve, when laboratory pump down of the IGRA is required.

Thermally conductive gaskets, assembled between each cover and the CMG frame, provide improved transfer from the frame to the covers, of heat generated by the frame mounted Electronics Assembly.

The covers can be seen in the photographs of the overall CMG, Figures 1.4.1.1-2 and -3.

1.4.1.8 Gimbal Stops

Energy absorbing gimbal stops are mounted to the CMG gimbals and frame, to limit the rotational excursion of both the inner and outer gimbal assemblies.

These devices mechanically limit inner gimbal travel to $\pm 80^{\circ}$ and outer gimbal travel to $\pm 175^{\circ}$.

The stop assemblies have been designed to meet the following three requirements:

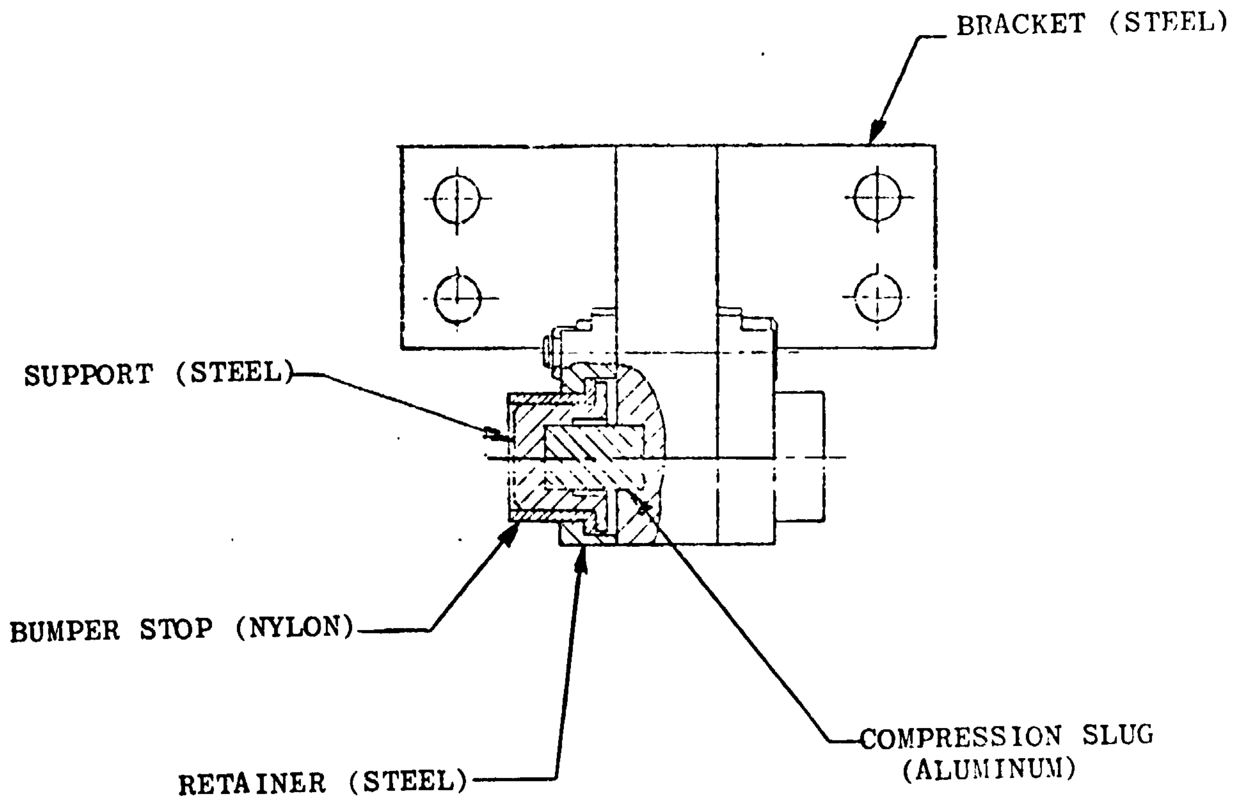
1. For repeated low velocity impact loads, which could be imposed under normal operation, the stops must be elastic and have a spring rate low enough to bring the gimbals to rest without exceeding the allowable gear train torque of 560 ft lb. For this condition, which may be repeated any number of times, it is assumed that the gimbal strikes its stop at an initial velocity of .08 rad/sec and that an actuator output torque of 222 ft lb acts throughout the stopping stroke.
2. In the event of a gimbal rate loop failure, either gimbal could strike its stop at an initial velocity of 0.48 rad/sec with an actuator output torque of 222 ft lb acting throughout the stopping stroke. In this instance also, the stop must bring the gimbal to rest without exceeding the allowable gear train torque of 560 ft lb. As this condition would indicate a CMG failure, precluding further use of the unit, the stop is allowed to deform permanently, since repetition of these loads would not be anticipated.
3. The stops must be capable of supporting a suddenly applied torque load of 960 ft lb, the maximum gyroscopic load that can be experienced. As this load is not reflected back to the actuator,

the stops need not function to protect the gear train, but are only required to stop the gimbals without fracturing and creating the possibility of loose pieces.

The stop configuration (typical) that is designed to satisfy the above requirements is shown in Figure 1.4.1.8-1. The active elements of the stop assembly are a nylon bumper and a soft aluminum compression slug which are separated by a steel support. These parts are held to the stop bracket by a steel retainer which contacts only the nylon bumper. The behavior of this design under the three load conditions given above is as follows:

1. For low velocity impact loads only the nylon bumper is active and the gimbals are brought to rest by means of elastic deformation of the nylon only. The calculated maximum stop load would result in torques of 485 ft lb and 500 ft lb on the inner and outer actuator gear trains, respectively. The nylon bumpers thus absorb the low velocity impact loads elastically without causing gear train loads in excess of 560 ft lb.
2. For high velocity impact loads both the nylon bumper and aluminum compression slug are active. The load applied at the nylon bumper is transferred by the support to the aluminum slug, which is sized to deform at a torque load of 560 ft lb.

   Immediately after impact, energy is absorbed elas-



GIMBAL STOP ASSEMBLY (TYPICAL)

FIGURE 1.4.1.8-1

tically by the nylon bumper as it deforms under increasing load. When the load approaches 560 ft lb the aluminum slug starts to yield in compression. No further increase in load can occur until the aluminum slug deforms sufficiently to allow the support to bear against the bracket. However, as the slug is designed to absorb by compressive yielding, all energy not absorbed by the nylon bumper, the gimbal is brought to rest before the support contacts the bracket.

Since the load required to compress the aluminum slug is 560 ft lb, the gear train is protected against excessive torques. This protection, however, is provided only once, and the aluminum slug must be replaced before repeating the high velocity impact load.

3. For the suddenly applied maximum gyroscopic torque load of 960 ft lb, the steel support is the active member. At this high load, the nylon bumper is compressed to its minimum length and the aluminum slug is compressed to its minimum height, so that the support flange bears directly on the bracket. Thus, both the support bracket and the opposing gimbal stop that it impacts, must be capable of carrying this maximum load. Stress analyses of these parts and their mounting hardware have been performed to assure that the detail design meets these requirements.

A series of static load-deflection tests were performed on both the inner and outer stop assemblies to confirm that the design requirements had been met.

The outer gimbal stop assembly is Bendix P/N 2120733-9. The stop bracket, fixed to the frame, that the stop assembly impacts is P/N 2120542-1.

The inner gimbal stop assembly is P/N 2120739-1. The stop brackets, fixed to the outer gimbal that the stop assembly impacts are P/N 2120740-1 and -2.

1.4.1.9 Evacuation Valve

A motor driven Evacuation Valve, mounted to the IGRA, provides the means to evacuate the sealed inner gimbal by pumpdown in the laboratory and, if desired, to vent the IGRA to space during orbital operation.

The valve, Bendix P/N 2120530-9, is a sealed assembly consisting basically of a housing, a brush type torque motor, a lead screw, a spring loaded poppet assembly and cam operated limit switches.

The housing, which is machined from aluminum alloy 2024T4, includes the mounting flange and port that interface with the IGRA and a fitting to accept a quick disconnect coupling of a laboratory pump hose line.

The torque motor is Inland NT-1389A, which uses brushes fabricated of Beoing compact 046-45. Rotary motion of the motor is converted to linear motion of the motor is converted to linear motion of the valve shaft by a lead screw, machined from aluminum alloy 2024. The .500-32 lead screw thread is coated with "Tufram", a proprietary conversion coating containing teflon, that provides the required lubrication between the lead screw and motor rotor.

The self centering poppet assembly is engaged with the valve seat, machined in the housing, by the advancing lead screw, and is securely held in the seated position by the force of a helical compression spring.

Cams, mounted to the moving lead screw, actuates limit switches which are closely adjusted at final assembly to operate at the full open and full closed positions of the valve. The switch circuitry includes diodes, terminal board mounted within the unit, and so arranged that the 28 VDC supplied to the motor is removed as soon as the travel extreme is reached. A third limit switch provides information to an external indicating light on the open or closed condition of the valve.

Angular contact bearings, with balls and races fabricated of 440C stainless steel, support the motor rotor assembly. The bearing retainers are made of teflon and the bearing races are coated with MLF-5, a molybdenum disulfide-sodium silicate dry film lubricant applied by Midwest Research Institute, Kansas City, Mo.

Final acceptance test of the Evacuation Valve is conducted in accordance with 2124139 (GTS) and includes checks of valve operation, sequence of switching, valve seat leakage, valve housing leakage and performance at reduced voltage.

1.4.1.10 CMG Electronics Assembly (CMGEA) Description

The CMGEA provides for gimbal rate servo control of the CMG inner and outer gimbals and it is mounted on the CMG frame as shown in figures 1.4.1.1-1, 2 and 3. Its major physical and interface characteristics are as follows:

Bendix P/N 2123400-19

Size: 8.6" x 9.8" x 3.0"

Volume: 0.15 cu. ft.

Weight: 8.2 lb.

Construction: Magnesium hog-out with one cover and vent.

Mounting: 10 point bolt attachment to the CMG frame.

External Finish: Pyromark (white)

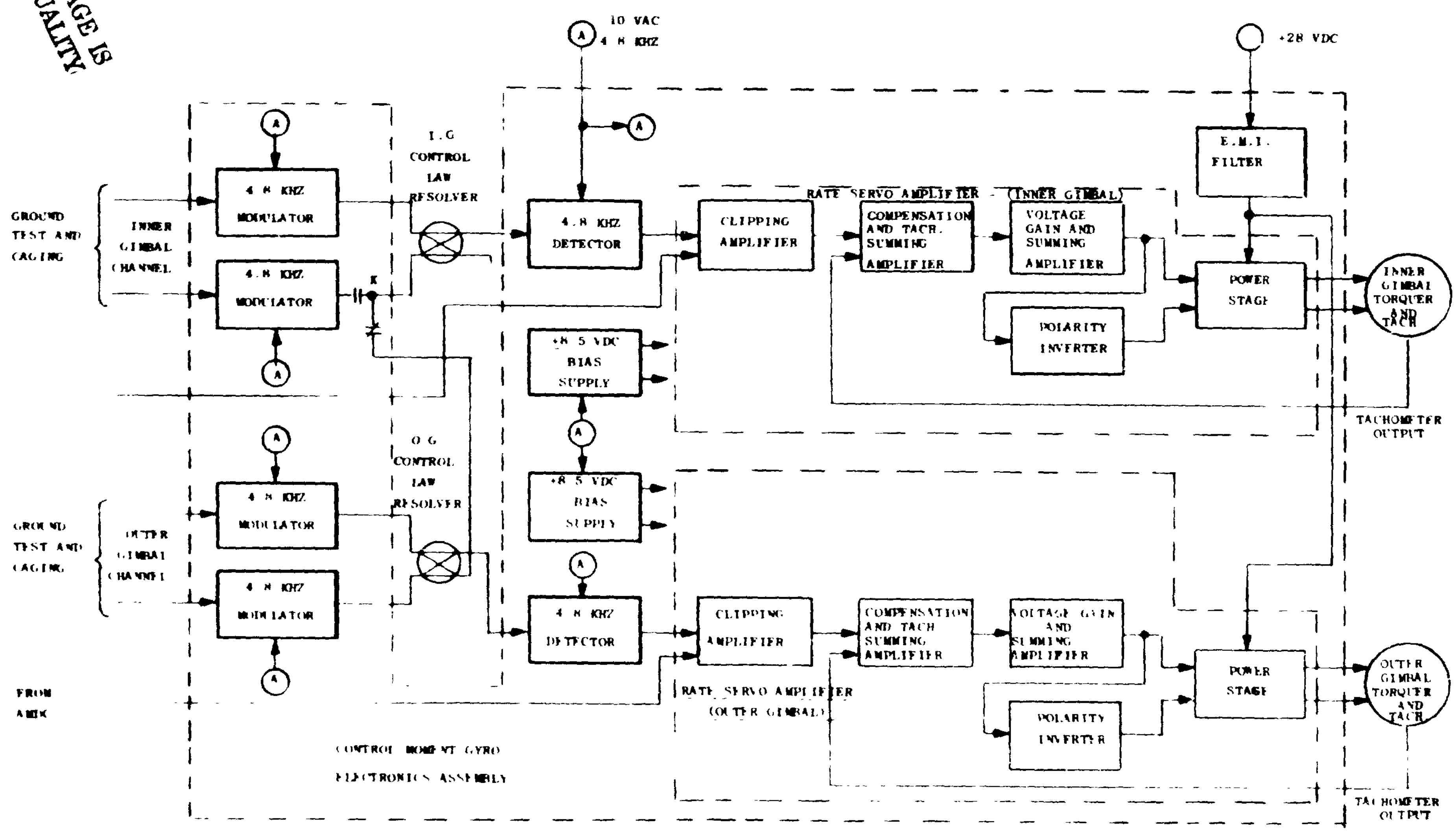
Heat Removal: Designed for only conduction to the CMG frame.

External Connectors: Three.

Internal Packaging: Seven modules, hard wired.
2 rate amplifiers - ruggedized.
2 bias supplies - potted.
2 modulator/detectors-potted.
1 EMI module - ruggedized.

A functional block diagram of the CMGEA is shown on Figure 1.4.1.10-1. It shows the unit to be comprised of two channels; one for inner gimbal rate control and one for outer gimbal rate control. Provision is made for ground test gimbal caging and other special ground testing by closing a position servo loop around the rate servo loop for each gimbal using the control low resolvers mounted on the CMG in its Sensor Pivot Assemblies.

The primary operating mode is the rate command mode. In this mode the gimbal rate command from the ATM Digital Computer is a differential analog DC.



FUNCTIONAL BLOCK DIAGRAM CMEA
FIGURE

1.4.2 CMG Inverter Assembly (CMGIA) Description

The CMGIA is a solid state electronics assembly that provides three basic functions as follows;

1. AC Power for the CMG Subsystem:
   3 phase, 455 Hz, 115 to 135 volts (line to line) - wheel spin motors
   1 phase, 4.8 KHz, 10 volts - gimbal angle resolvers
2. AC power for other ATM APCS equipment users.
   3 phase, 455 Hz, 115 to 135 volts (line to line)
   1 phase, 4.8 KHz, 10 volts
   1 phase, 800 Hz, 28 volts
3. Conditioning electronics for the CMG subsystem - for telemetry, display and special controls

Its major physical and interface characteristics are as follows;

Bendix P/N 2121500
NASA P/N 50M22137
Size: 22.5" x 25.0" x 3.5"
Volume: 1.15 cu. ft.
Weight: 49 lbs.
Construction: Magnesium hog-out with one cover and vent
Mounting: 16 point bolt attachment to the ATM rack
External finish: Pyromark (white)
Heat removal: Designed for only radiation to space and surroundings on the ATM rack
External connectors: seven

Internal Packaging:

a. High current square waves are kept behind an interval RFI wall
b. RFI capacitors through the RFI wall connect signals between circuitry
c. Three phase power confined in one harness to one area so as to minimize interference with other circuitry
d. Potted and ruggedized modules interconnected with hard wires.

The photograph in Figure 1.4.2-1 shows the completed CMGIA. Figure 1.4.2-2 shows the IA with its cover removed. In this view the RFI wall can be seen at the approximate center of the module area. The left side of the picture shows the six potted output transformers and their six potted power amplifiers for the 3 phase, 600 VA inverter power. A precision oscillator module, frequency divider module, $\pm$12 VDC power supply (for all CMGIA circuits) and 3 phase output filters are seen from the top down in this inverter section. The right side of the picture shows the area containing a 28 VDC line filter, conditioning electronics, control functions and the 4.8 KHz and 800 Hz power supply modules. The conditioning electronics and control functions include;

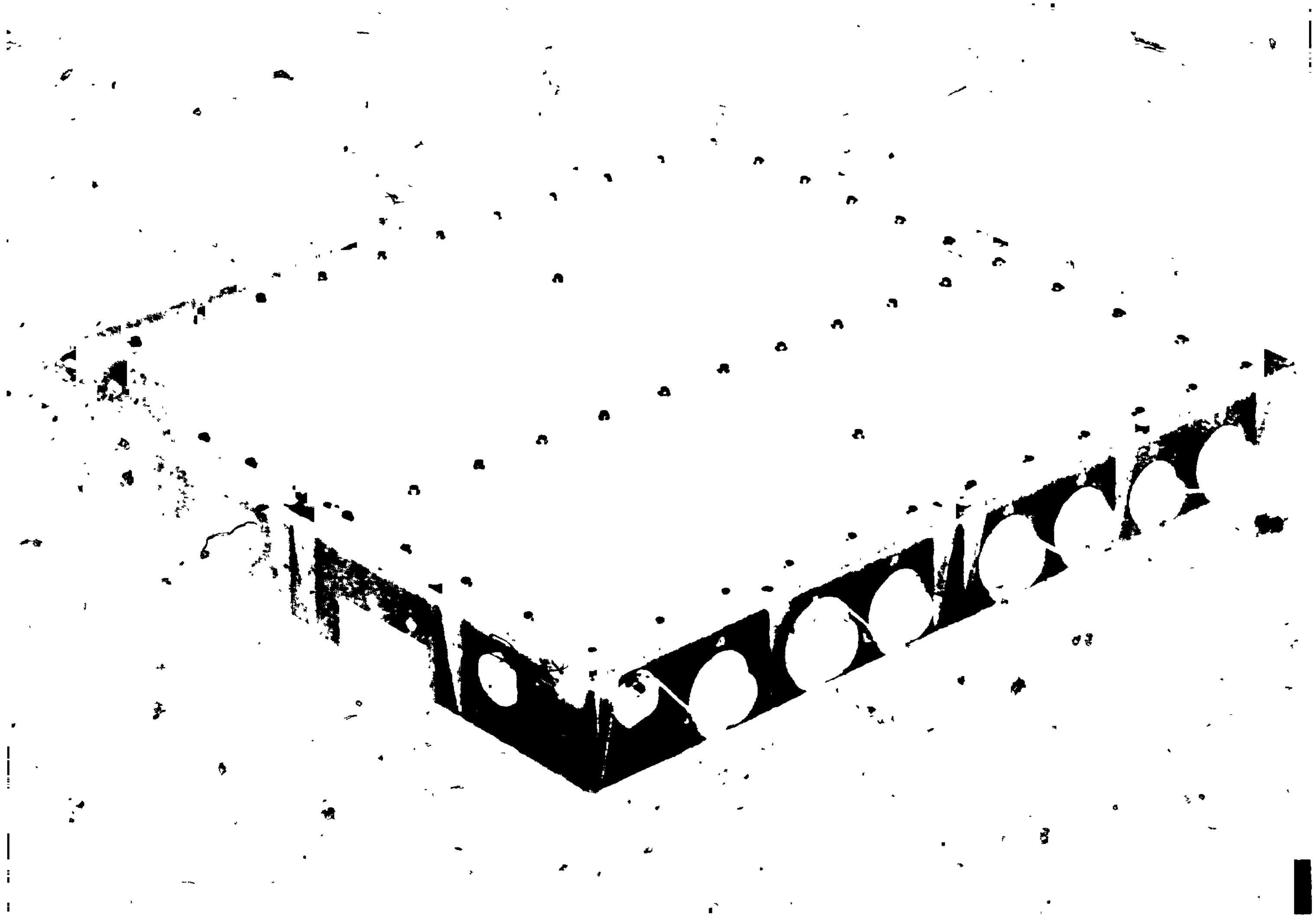
For telemetry and display;

1. CMGIA temperature
2. The three phase inverter line currents to the CMG wheel spin motors

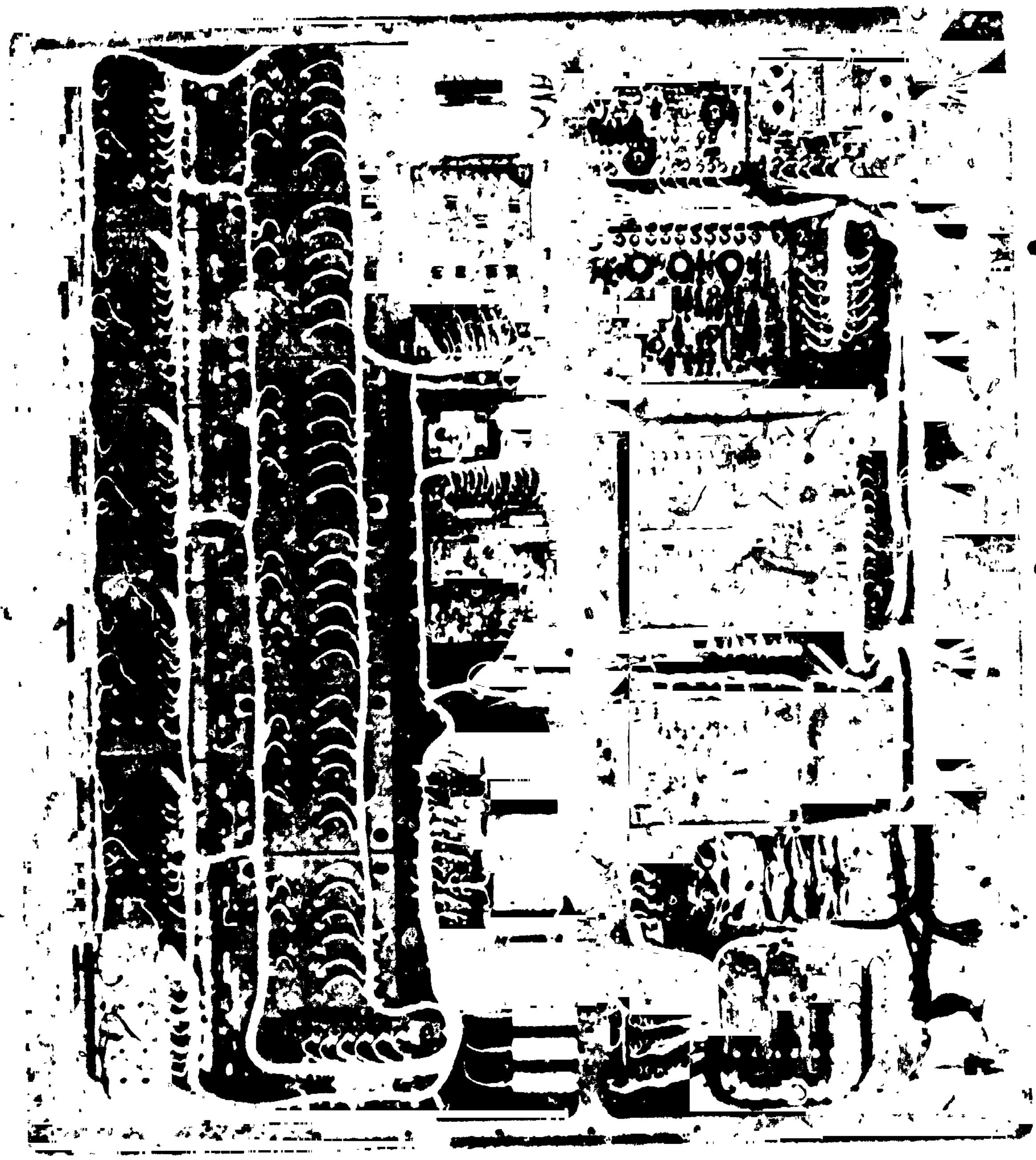
3. Wheel speed (pulse to DC)
4. Spin bearing temperatures (including a $160^{\circ}F$ caution discrete)
5. Inner and outer CMG gimbal angle. Linearized and conditioned gimbal resolver signals

For control;

1. CMG wheel dc brake power supply and relay
2. Automatic thermostatic control circuit and relays for the CMG spin bearing heaters
3. Automatic CMG wheel shutdown circuit based on spin bearing temperature - with provision for astronaut override
4. Turn on and relay functions; conditioning electronics on, inverter on, CMG wheel on, CMG wheel dc brake on, CMG EA on.



CMG INVERTER ASSEMBLY
FIGURE 1.4.2-1



1.5 LIFE TESTING

1.5.1 Inner Gimbal and Rotor Assembly (IGRA)

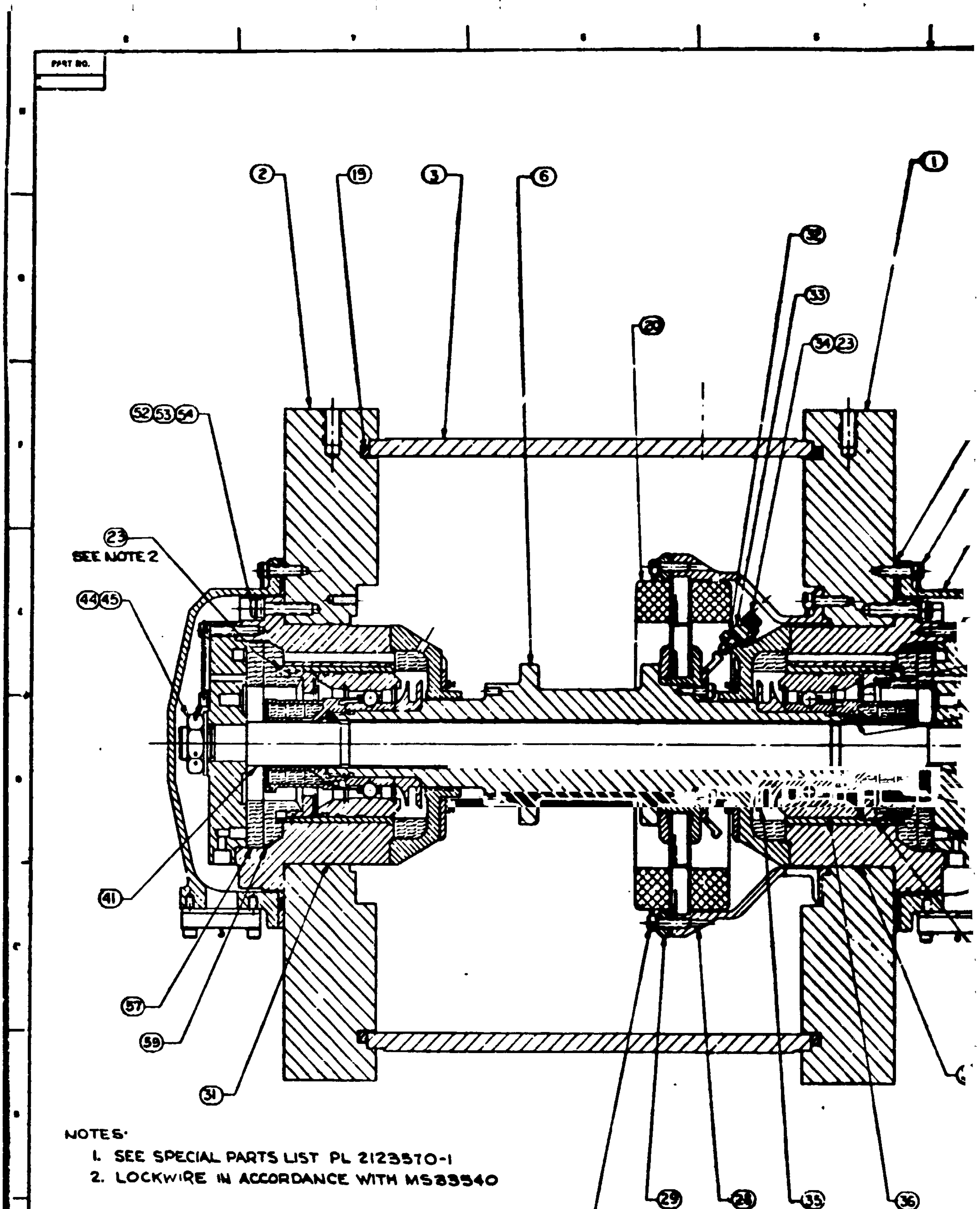
Three of the fifteen inner gimbal and rotor assemblies produced by Bendix Guidance Systems Division were engineering units assigned to special testing and life testing. Unit E-1 and E-2 were delivered to NASA MSFC for special testing. Unit E-1 was assigned to environmental testing, i.e. thermal and vibration tests. Later this unit was retrofitted into a brushless dc unit as part of contract NAS 8-25756. Unit E-2 was life tested with the anticipated torque profile duty cycle. Unit E-3 was retained at Bendix for life and offgassing testing. At the completion of all testing, these units had accumulated the following hours:

Unit	Hours
E-1	4,450
E-2	26,750
E-3	24,089

Spin bearing life test fixtures were designed and constructed by Bendix Guidance Systems Division to test the 107 angular contact ball bearings used in the ATM CMG. These test articles were designed to simulate the actual CMG inner gimbal and rotor assembly operation as it would occur under zero "g" conditions.

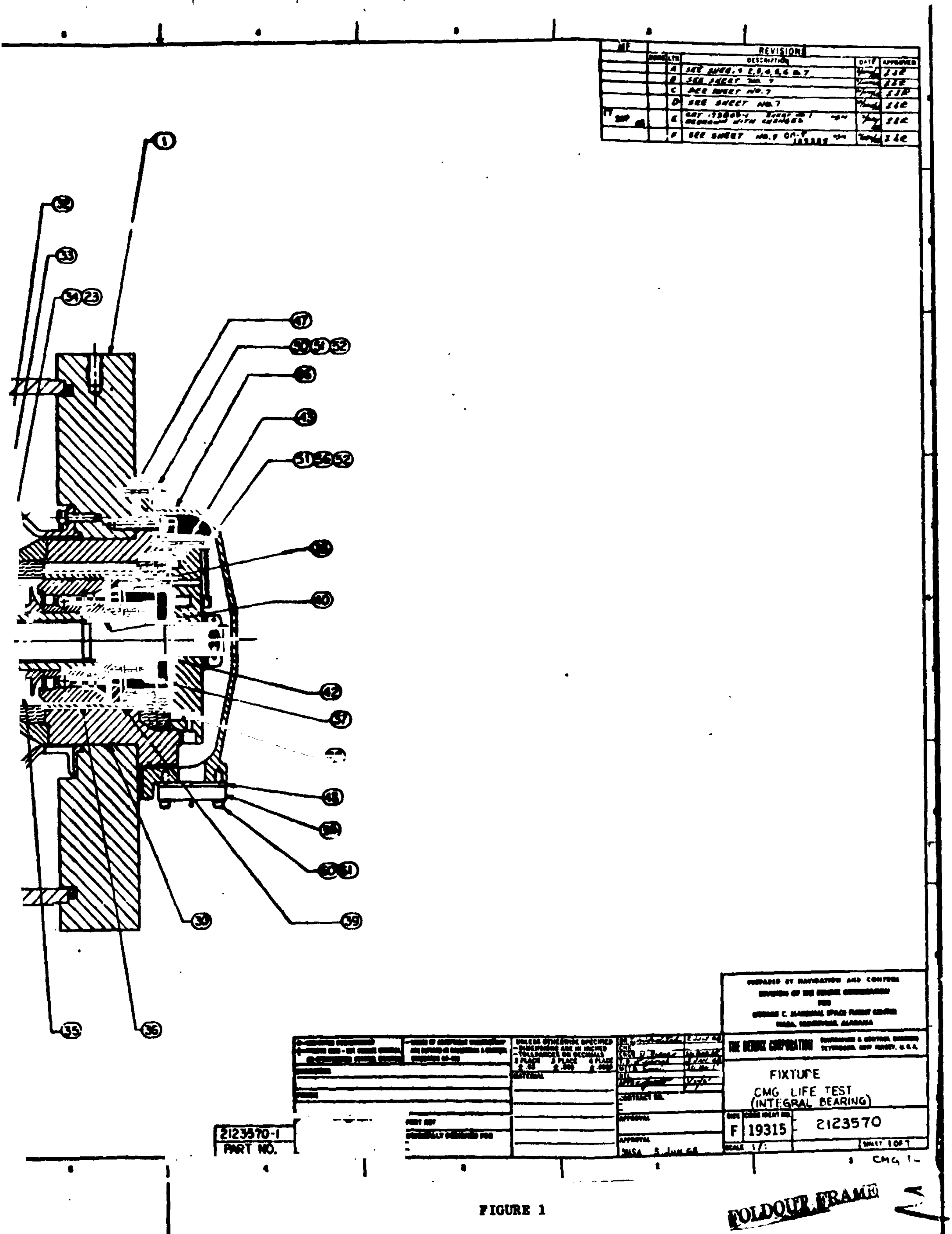
The life test fixture as shown in Figure 1 (ref: drawing no. 2123570-1) was designed to include the following features:

C-2



NOTES:

1. SEE SPECIAL PARTS LIST PL 2123570-1
2. LOCKWIRE IN ACCORDANCE WITH MS33540



REVISIONS
THE BENDIX CORPORATION
FIXTURE
CMG LIFE TEST
(INTEGRAL BEARING)
F
19315
2123570
2123570-1
PART NO.
FOLDOUT FRAME

FIGURE 1

a. One actual CMG spin motor
b. Low weight shaft to simulate approximately .06 - .07g.
c. Identical bearing support housing to CMG, except fabricated from aluminum rather than beryllium
d. Identical stiffening strut, end caps, laybrinth, slinger, housing cover, to actual CMG
e. Speed, bearing vibration, bearing temperature and vacuum monitors
f. Cartridge heater plus additional strip heater capability for increasing operating temps
g. Vacuum seal and valving capability

The purpose of the Engineering Life Test Program was to demonstrate the operating life and reliability of the flight configuration bearing (107H angular contact ball bearing) and lubricant system. This was performed under conditions which most nearly simulated actual CMG operating parameters.

All of the bearing life testing was performed at a vacuum level of approximately 10 microns and at an operating speed between 8000 and 9100 rpm.

Throughout the course of the life tests, the following parameters were periodically monitored:

a. Left and right bearing vibration level
b. Left and right bearing temperature
c. Unit speed
d. Unit pressure
e. Bearing torque (rundown method)

Six (6) bearing sets, SBB 006 and 011, 007, 008, B-6 and B-7, S-010 and S-013, S-003 and S-012, B13 and B-10 were thoroughly inspected and then assembled with their separators. The separators were vacuum impregnated at 180°F with KG 80 oil and were centrifuged at 300 g for 15 minutes after assembly.

The separators were of a design utilizing undercut and scalloped ODs. The separator side faces were also undercut to facilitate assembly of and to receive oil from the bearing lubricant system. Three (3) .029 dia. holes per side were drilled from the undercut to the separator OD to help distribute the oil to the bearings.

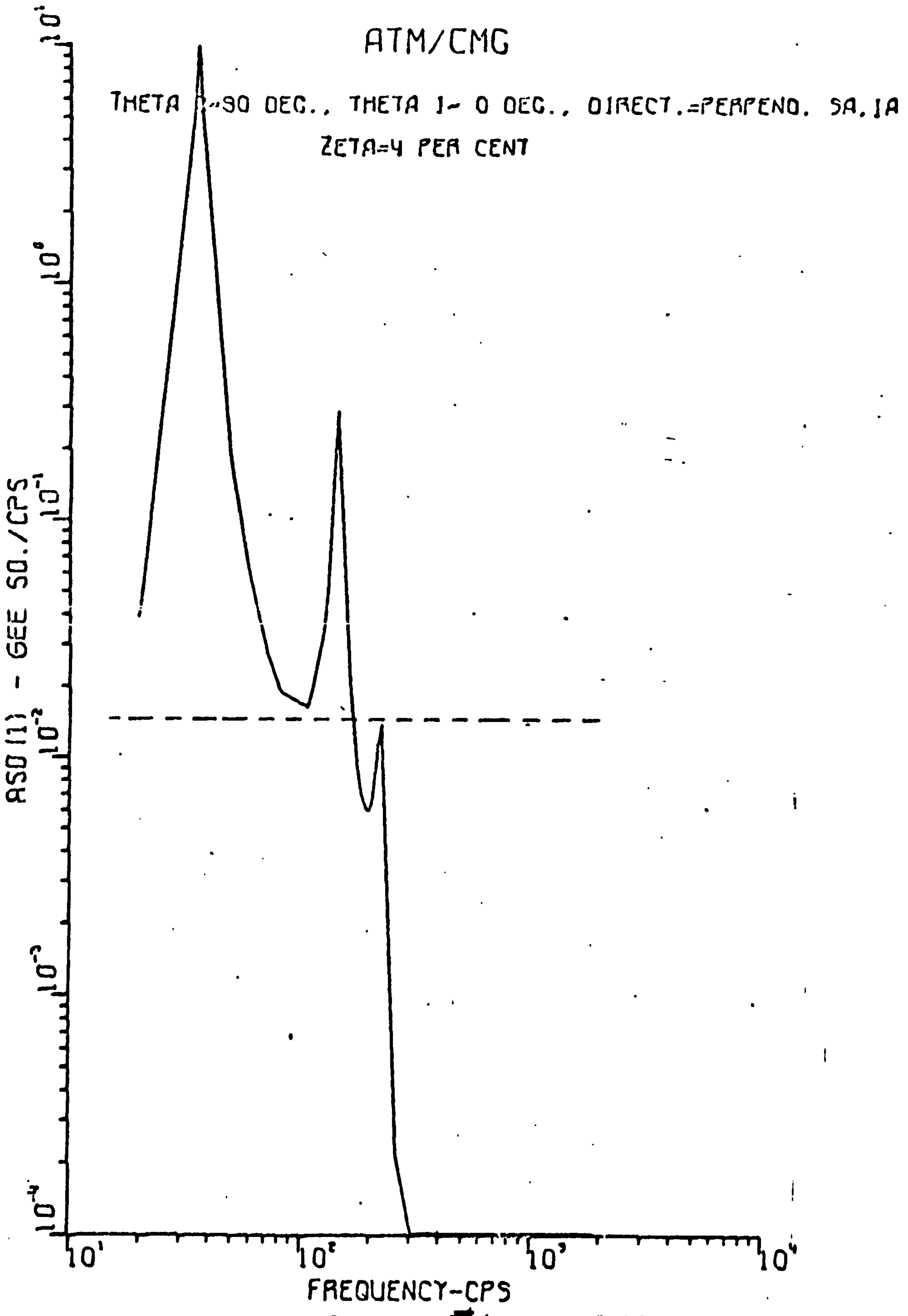
Bearing sets (006 and 011, 007 and 002) were then assembled into the bearing torque test fixtures and run up to 7800 rpm. The torque values were then recorded per the following program.

a. Run to 7800.
    1. Run 5 minutes and record torque level.
b. Run at 7000, 6000, 5000, 4000, 3000, 2000, 1000 rpm.
    1. Run 5 minutes and record level.
c. Run at 7800 rpm for 4 to 16 minutes.
    1. Record values at end of each hour.
d. Repeat step b.

The bearings were then removed from the test fixture, extra oil added to the separators, and the bearings shipped to Astrionics to be subjected to vibration per Graph No. 1. The curve of acceleration spectral density

ACCELERATION SPECTRAL DENSITY

ATM/CMG



Graph #1

represents the random energy levels the CMG spin bearings will be subjected to during the boost phase of the Skylab mission. The length of test was one minute.

After undergoing this test the bearings were returned to Bendix and were visually inspected.

Since no visible damage was noted, the bearings were recentrifuged at 15 g's for five (5) minutes each. Steps 1 through 4 of the torque test program were then repeated, and the torque levels recorded. The bearings were then assembled into life test fixtures S/N 2 and 3 and put on life test.

Barden bearings B-6 and B-7, S-010 and S-013, S-003 and S-012, and B-13 and B-10 were also run through the above torque procedure on the bearing torque test fixture but were not subjected to the vibration tests. They were assembled directly into life test fixture S/N 1, 4, 5, 6, respectively.

The life test fixtures and bearing serial numbers are as follows:

LTF No. 1	Barden 6 and 7
LTF No. 2	SBB 006 and 011
LTF No. 3	SBB 007 and 008
LTF No. 4	SBB 010 and 013
LTF No. 5	SBB 003 and 012
LTF No. 6	B-13 and 10

The test program for these six bearing test fixtures was as follows.

LTF	Brg Type	Lube Sys.	Temp °F	Brg Cond.
1	Integral	Dyn. Nut	Room Temp	Virgin
2	"	"	Orbital	Qual Vib.
3	"	"	Room Temp	Qual Vib.
4	"	"	"	Virgin
5	"	"	Orbital	"
6	"	"	160-180°F	"

Table 1 that follows is a summary of the ATM CMG Spin Bearing Life Test Fixture Test Program as of its completion on October 25, 1973.

UNIT #	INITIAL RUNNING HRS 8000 RPM	PRESENT RUNNING HRS 9100 RPM	TOTAL HRS	LUBE FLOW RATE 90°F MG/HR	COMMENTS
LTF #1	21,100	16,408	37,508	0.15	virgin
LTF #2	27,300	-	32,380	1.50	brg subject to launch vib prior to run
LTF #3	20,500	18,608	39,109	0.015	same as 2
LTF #4	26,800	-	28,850	0.040	run at 160-180°F, ambient
LTF #5	17,300	8,229	24,089	0.060	-
LTF #6	16,800	19,890	36,690	0.060	first 500 hours room temp next 1600 hrs 160°F remaining hrs 190°F

TABLE 1

1.5.2 Actuator Pivot Assembly

Prior to the establishment of the final flight configuration of the CMG Actuators, several life test programs were performed on designs that existed at interim stages of development. These tests, which were influential in guiding the design to its final configuration, are briefly described in this section.

Early in the program, when the mission life requirement was 56 days, an actuator using dry lubrication for the ball bearings and gear train, successfully passed a real time test of 56 days, operating in a vacuum to loads and speeds of an estimated duty cycle. (See letter R-P and VE-MEL-68-33, dated August 15, 1968). Although this test proved the capability of the unit to meet the life requirement that existed at the time, an additional 30 days of operation resulted in significantly degraded performance and led to the conclusion that a dry lubrication system could not meet the newly increased life requirement of 300 days.

During the following period of time, while Battelle was reviewing the actuator design and evaluating wet lubrication systems, an interim unit was converted to wet lubrication and subjected to duty cycle testing in a vacuum at MSFC. As test failures occurred and inputs became available from Battelle's studies, the unit was modified and, although it did not incorporate all of the changes required to bring it to flight configuration, it completed 304 days of successful operation.

After the actuator flight configuration was ultimately established and built, three units were assigned to life test programs conducted at MSFC as follows:

a. One unit was subjected to 300 days of real time testing, operating to loads and speeds of a duty cycle generated by MSFC.
b. One unit was operated to an accelerated duty cycle, established by Battelle, with loads and speeds selected to verify gear and bearing wear life.
c. One unit was operated to a Battelle established accelerated duty cycle, with loads and speeds selected to confirm the units' ability to withstand cyclic stresses and fatigue.

Development of the accelerated test sequences used is described in Battelle's "Design Review of a CMG Actuator".

Testing was performed using a Bendix fabricated load fixture, in which the actuator output shaft was coupled through a 1:25 gear ratio to a Magtrol hysteresis brake. Automatic application of the duty cycle was provided by a test set that included actuator rate loop electronics and timing motor driven cams, operating relays that selected the required level of Magtrol torque, actuator rate and direction of rotation.

When testing was terminated, none of the three units showed any degradation of their originally recorded performance characteristics. When disassembled for inspection, all gears, ball bearings, motor and tachometer brushes and commutators, lubrication and seals were in "as new" condition.

Based on the results of these tests, it was concluded that the actuator life expectancy was far in excess of the mission life requirements.

1.5.3 Sensor Pivot Assembly

Although no life test was performed on a full sensor assembly, testing was performed on those sensor components that would be subject to wear or fatigue. The only items in this category were the flex lead assembly and the pivot bearings.

1.5.3.1 Flex Lead Assembly

Cycling tests were performed on flex lead assemblies, using the test fixture shown in Figure 1.5.3-1. This fixture simulated the motion that would be experienced by the sensor with the greater excursion limits. The center connector, Figure 1.5.3-2, was rotated $\pm 178^{\circ}$ (one cycle), with the stationary leads being held in the shaped nylon flex lead guide. Continuity of the circuits was continuously monitored to provide evidence of satisfactory performance. The wire material, insulation, insulation etching, connector configuration, potting material and wire lacing were identical to that used in the sensor itself. This test was, in fact, used to develop the optimum selection of materials and configuration.

Before the ultimately selected flex lead assembly was subjected to life test cycling, it was given the following random vibration exposure in each of the three mutually

FLEX LEAD TEST FIXTURE
FIGURE 1.5.3-1

CENTER CONNECTOR
FLEX LEAD TEST ASSEMBLY
FIGURE 1.5.3-2

perpendicular axes, for three minutes per axis. Continuity checks before and after vibration, verified the integrity of all circuits.

10-35 Hz	+6db/oct
35-100 Hz	$0.25g^2$/Hz
100-150 Hz	-24db/oct
150-400 Hz	$0.01g^2$/Hz
400-2000 Hz	-2.25db/oct
2000 Hz	$0.00343g^2$/Hz

Cycling in the test fixture at room temperature was then initiated, with the first five failures as follows:

Failure #	Wire Gage	Cycles	Time (hrs)
1	22	55,722	109.8
2	22	61,649	121.5
3	22	105,418	207.8
4	22	231,361	456.3
5	22	271,971	536.3

After the fifth failure, as other 22 ga circuits were showing signs of being near failure, monitoring of all 22 ga circuits was stopped.

Cycling continued with all 28 ga circuits being monitored, until 907,382 cycles were completed, 1788.5 hrs after the start of test. At this point, no 28 ga circuit had failed and this portion of the test was concluded.

The flex lead test assembly was then rewired as before except that two lacing ties were added to the wire bundle, a change that was also made to the actual sensor units. The assembly was then subjected to life test cycling at $-40^{o}F$. The first failure, of a 22 ga wire, occurred after 188,688 cycles, at which point the test was terminated.

As both room and low temperature life tests far exceeded the original design life goal of 20,000 cycles that had been conservatively established early in the Skylab program, it was concluded that the flex lead configuration used in the sensor pivots was acceptable.

It should be noted that realistic duty cycle data, developed later in the program by MSFC, verified that the total anticipated gimbal excursion would be far less than the 20,000 cycle standard that had been originally applied.

1.5.3.2 Pivot Bearings

A wet lubricated duplex bearing pair, the part used in both sensors and actuators as the gimbal pivot bearing, was subjected to life test operation in a vacuum at MSFC.

The test was conducted on a bearing mounted in an ATM actuator that had been converted to a direct drive unit by removing the gear train and substituting a shaft that coupled the motor directly to the output shaft. A weight mounted to the output shaft was sized to apply a radial load of 58.5 lb to the pivot bearing. This was the value equal to the pivot bearing load resulting from maximum gyroscopic torque with continuous rotation of the gimbal at maximum rate.

As the test unit was driven open loop, the rate could not be steadily applied at the maximum gimbal rate of 3.5 deg/sec and had to be increased to 20 rpm. This was considered satisfactory, as lubrication still remained in the boundary mode, with velocities too low to produce a hydrodynamic film.

Alternating directions of rotation, the unit was operated for 5553 hours, resulting in approximately 6,600,000 total output shaft revolutions. Based on early Bendix approximations of the CMG duty cycle, the output shaft would experience 16.8 rev/orbit or 269 rev/day. The test duration was thus equivalent to approximately 24,500 days of CMG operation.

Examination of the unit after termination of testing, showed the bearing to be in "as new" condition. It was evident that the bearing and lubricant selected were satisfactory for mission use.

1.6 RELIABILITY

The following reports, "Failure Mode, Effects and Criticality Analysis of the CMG Assembly for the ATM CMG Subsystem (RE70-294)", June 17, 1970, and "Failure Mode, Effects, and Criticality Analysis of the Inverter Assembly for the ATM CMG Subsystem (RE71-157)", June 30, 1971, combine a Reliability Prediction, Failure Mode and Effects Analysis and Criticality Analysis.

The results of these analyses are as follows:

I. Prediction

a. Mean Time to First Failure
   1. CMG EA - 27,669 hours
   2. CMG IA - 56,798 hours
   3. CMG Subsystem (EA plus IA) - 18,606 hours
   4. 3 CMG Subsystems - 6,202 hours

   For the survival of 2 out of 3 subsystems configuration the mean time to second failure is 15,505 hours.

b. Probability of Survival and Mean Time to Redundant Failure for a 240-day mission.**
   1. CMG EA - 0.9456
   2. CMG IA - 0.9768
   3. CMG Subsystem (EA plus IA) - 0.9237
   4. Survival of 2 out of 3 subsystems - 0.9834

   The associated mean time to redundant failure is 345,688 hours.

   *Based upon total failure rate of 36.141 x 10^{-6} (EA) and 17.606 x 10^{-6} (IA) parts per hour, respectively. The total failure rate is equal to the sum of the failure rates of all parts contained in the EA and/or IA.

**Based upon the net failure rate of 9.708×10^{-6} (EA) and 4.067×10^{-6} (IA) parts per hour, respectively. The net failure rate is equal to the total failure rate less the failure rate associated with non-critical failure modes.

II. Criticality Analysis

Criticality for a 240 day mission**.

a. CMG EA - 55,928
b. CMG IA - 23,428
c. CMG subsystem - 79,356
d. 3 CMG subsystems (survival of 2 out of 3 required) - 16,706

III. Failure Mode and Effects Analysis

The FMEA Summary pages for the CMG EA and IA are located at the end of this section.

IV. Single Point Failures

Since the CMG subsystem and its constituent units (EA and IA) are all non-redundant, all parts (except those associated with non-critical outputs) are single point failures.

**Items marked thus (*) do not operate in flight

FAILURE EFFECT ANALYSIS

C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on 1 C.M.G. Assembly Performance	Failure Effect on	Failure Effect
C.M.G. Assembly (I)				The CMG Assembly is a double gimbal control moment gyro capable of producing controlled torques about either gimbal axis. The torques are responses to command signals received from an external source which controls the gimbals. The CMG Assembly consists of the following circuits (for details refer to the blocks listed):				
				1. Spin Motor Circuit Blocks 2.1-1, 2.1-2, 4.0 (Misc.), 6.0 (Misc.), and 7.0.	No Output	Total Loss Failure of CMG Assembly — inability to rotate spin wheel.		
				2. Gimbal Circuits Blocks 1.1.1, 1.1.2, 1.1 (Misc.), 1.2.1, 1.2.2, 1.2 (Misc.), 1.5, 1.4, 1.0 (Misc.), 3.1, 3.2, 5.1, 5.2, 4.0 (Misc.), 6.0 (Misc.) and 7.0.	No Output	Probable Loss May result in inability to operate Inner/Outer Gimbals.		
				Blocks 1.1.1, 1.1 (Misc.), 1.2.1, 1.2 (Misc.), and 1.0 (Misc.).	Increased Output	Possible Loss Increase in rate of Gimbal Travel, Torque, and Circuit Stresses.		
				Blocks 1.1.1, 1.2.1.	Decreased Output	Possible Loss Decrease in rate of Gimbal Travel and Torque; insufficient response.		
				Blocks 1.1.1, 1.2.1, 1.1 (Misc.), and 1.2 (Misc.).	Distorted Output	Possible Loss Erratic Gimbal Control.		
						Issue Date	Prepared by.	Approved:

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FAILURE EFFECT ANALYSIS

C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on 1 C.M.G. Assembly Performance	Failure Effect on	Failure Effect
				3. "H" Feedback Resolver Circuits Blocks 4.2, 6.2, 6.0 (Misc.), 7.0, and 1.0 (Misc.).	No Output	Total Loss Inability to provide Inner/Outer CMG Gimbal Position Data to Digital Computer.		
				Blocks 4.2 and 6.2.	Dist. Output	Possible Loss Inaccurate Data on Inner/Outer CMG Gimbal Positions fed to Digital Computer.		
				4. Evacuation Valve Blocks 2.3, 4.0 (Misc.), 6.0 (Misc.), and 7.0.	No Output	Possible Loss Negligible		
				5. Limit Switch Circuits Blocks 4.4-1, 4.4-2, 6.4-1, 6.4-2, 6.0 (Misc.), and 1.0 (Misc.).	No Output	Possible Loss Loss of ability to Display Data on extremes of Inner/Outer Gimbal Travel. Also failure of protective circuits which prevent the Servo Amplifiers from driving the Gimbals against a physical stop and overheating the torquer motors.		
				6. a) Caging Circuits Blocks 1.3-1, 1.3-2, 1.5, 4.1, 6.1, and 6.0 (Misc.) b) Elapsed Time Indicator Circuit Blocks 8.0, 7.0 and 6.0 (Misc.).	All Failure Types	No Effect Failure of circuits not required in orbit.		

Issue Date:	Prepared by:	Approved:

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FAILURE EFFECT ANALYSIS
C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on 1 C.M.G. Assembly Performance	Failure Effect on	Failure Effect
				7. a) Linear Resolvers Blocks 4.3, 6.3, 7.0, 6.0 (Misc.), and 1.0 (Misc.).	All Failure Types	No Effect Loss of outputs used only for: a) Telemetry, Display, and Test.		
				b) Wheel Speed Pick-up Blocks 2.4, 4.0 (Misc.), 6.0 (Misc.), and 7.0.		b) Telemetry, Display, and Test.		
				c) Bearing Thermistor Outputs Blocks 2.6-1, 2.6-2, 4.0 (Misc.), 6.0 (Misc.), and 7.0.		c) Telemetry and Test (Also auto shut-down function -- refer to Blocks 2.6-1 and -2).		
				d) Outer Sensor Thermistor Blocks 6.5, 7.0, and 1.0 (Misc.).		d) Telemetry and Test		
				e) Evacuation Valve Indicator Output Blocks 2.3, 4.0 (Misc.), and 7.0.		e) Display and Test		
				f) Tach. Telemetry Outputs Blocks 1.1.1, 1.2.1 1.0 (Misc.), and 7.0.		f) Telemetry and Test		
				8. a) Bearing Heaters Blocks 2.7, 4.0 (Misc.), 6.0 (Misc.), and 7.0.	No Output	No Effect		
				b) RFI Filter Block 1.4.	Distorted Output			
						Issue Date:	Prepared by:	Approved:

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FAILURE EFFECT ANALYSIS

C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on Inverter Assembly	Failure Effect on CMG Subsystem	Failure Effect
Inverter Assembly (II)		2121809	II	The CMG inverter consists of a solid state A.C. power supply, and conditioning electronics.	455 HZ Outputs			
					No Output	Total Loss Loss of 130 V., 455 HZ outputs.	Total Loss Inability to power motors that drive the spin wheel.	
				The A C. power supply produces three outputs: (1) 130 V., 455 HZ (2) 28 V., 800 HZ (3) 10 V., 4.8 KHZ	Increased Output	Possible Loss All 455 HZ outputs increased.	Possible Loss CMG wheel motors operating under higher stress conditions - gain change.	
					Distorted Output	Possible Loss All 455 HZ outputs distorted.	Possible Loss Spin wheel speed variations.	
				The conditioning electronics receives signals from the linear resolvers, wheel speed pickoff, and bearing thermistors of the CMG assembly. The outputs of the conditioning electronics provide data for telemetry, test, and display and also controls the heaters in the CMG assembly.	800 HZ Output			
					No Output Increased Output Distorted Output	No Effect All 800 HZ outputs lost, increased, or distorted.	No Effect	
					4.8 KHZ Output			
					No Output	Total Loss Loss of all 4.8 KHZ outputs.	Total Loss Inability to drive inner and outer gimbals.	
				The inverter also contains circuits that control the DC brake and the evacuation valve and provides a filtered 28 V. DC output to the CMG electronics assembly.	Increased Output Decreased Output	Possible Loss 4.8 KHZ outputs increased or decreased erroneous inner gimbal position data from linear resolver Electronics (II-9.0).	Possible Loss Rate of inner and outer gimbal travel increased or decreased. Erroneous linear resolver data on gimbal position.	
				In addition, the inverter assembly feeds signals to/from the following CMG assembly circuits: (1) Vacuum gauge (2) Limit switches (3) Vibration sensors (4) C.M.G. EA (Tach. Telemetry and Demodulator outputs)	Distorted Output	Possible Loss 4.8 KHZ outputs distorted. Inner gimbal position data from linear resolver electronics distorted.	Possible Loss Erratic inner and outer gimbal response. Unstable gimbal position data from linear resolvers.	
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FAILURE EFFECT ANALYSIS
C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on Inverter Assembly	Failure Effect on CMG Subsystem	Failure Effect
Inverter Assembly (Continued)				Telemetry and test outputs of individual 455 HZ phase currents, and inverter operating temperature is also provided.	28 V. D.C. No Output	Total Loss Loss of 28 V. D.C. output to CMG electronics assembly.	Total Loss Inability to operate inner and outer gimbals.	
					Distorted Output	Possible Loss Distorted 28 V. D.C. output to CMG electronics assembly.	Possible Loss Erratic inner and outer gimbal control.	
					Conditioning Electronics Outputs No Output	No Effect	No Effect Loss of gimbal position, spin wheel speed, and spin wheel bearing temperature data for telemetry, test and display. Inability to control bearing heaters.	
					Increased Output Decreased Output Distorted Output	No Effect	No Effect Erroneous or erratic data on gimbal position, spin wheel speed, and spin wheel bearing temperature data for telemetry, test, and display. Erroneous or erratic activation or deactivation of bearing heaters.	
					D.C. Brake No Output	No Effect Inability to supply a DC brake voltage to one phase of the three phase output to the CMG spin motors.	No Effect Inability to quicken spin wheel deceleration.	
					Decreased Output	No Effect D.C. braking voltage decreased.	No Effect Spin wheel deceleration slower.	
					Distorted Output	No Effect	No Effect	
						Issue Date:	Prepared by:	Approved:

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FAILURE EFFECT ANALYSIS
C.M.G. SUBSYSTEM

Item	**	Drawing Number	Elect. Ref Desig	Function	Failure Type	Failure Effect on Inverter Assembly	Failure Effect on CMG Subsystem	Failure Effect
Inverter Assembly, (Continued)					Auxiliary Outputs No Output	No Effect	No Effect Loss of telemetry/test/display outputs from: (1) Vacuum Gauge (2) Evacuation Valve (3) Inverter Thermistor (4) Electronics Assembly Thermistor (5) Frame Thermistor (6) Vibration Sensors (7) CMG Servo Amplifiers (Tach. Telemetry output) (8) CMG Modulator-Detector (Demodulator output) (9) Output Current Assembly (rectified current output) (10) 19.2KHZ osc. test. Possible Loss Failure of evacuation valve possibly resulting in inability to completely exhaust the spin wheel cavity. Failure of the limit switch(es) may result in inability to prevent gimbal motor overheating under certain conditions.	
						Issue Date:	Prepared by:	Approved:

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SECTION 2

ATM CONTROL COMPUTER (ATM/CC)

AND

ATM EXPERIMENT POINTING ELECTRONIC ASSEMBLY (ATM/EPEA)

2.1 INTRODUCTION

At the beginning of contract NAS 8-20661, the contract included a separate piece of equipment whose function was to provide analog processing electronics for ATM vehicle pointing control as well as ATM experiment package pointing control. The equipment was designated ATM Control Computer (ATMCC). The ATMCC was to be non-redundant and two units were to fly to provide redundancy. Two ATMCC units were designed, developed, fabricated, assembled, tested and delivered to MSFC. The first was an engineering unit and the second a prototype unit. At about the time of the major program change from the dry Skylab workshop and 56 day mission to the wet Skylab workshop and 300 day mission (ultimately 270 days), MSFC issued a major contract change to delete the ATMCC and provide, instead, the ATM Experiment Pointing Electronic Assembly (ATM/EPEA). The EPEA was to provide only experiment package pointing control, dual redundant in one assembly. Six EPEA units were designed, developed, fabricated, assembled, tested (including qualification testing) and delivered to MSFC. Much of the circuitry, circuit cards, box package, piece parts, spare parts and test equipment developed for use in the ATM/CC effort was used in the ATM/EPEA equipment and testing. The descriptions that follow cover primarily the prototype ATM/CC and the flight configuration ATM/EPEA.

2.2 SUBSYSTEM DESCRIPTIONS

2.2.1 Apollo Telescope Mount Control Computer (ATMCC)

The Apollo Telescope Mount Control Computer (ATM CC) is an electronic control device and subsystem used in the Pointing Control System of the Apollo Telescope Pointing Experiment. It contains the signal processing circuitry whose two main tasks are:

1. To provide vehicle control for the ATM vehicle configuration by generating three axis momentum commands for the gimbals of the three double-gimballed CMG units.
2. To provide control for the Experiment Pointing System (EPS) by generating three axis gimbal torquer drive currents for the telescope's gimbal torque motors.

The input signals to the ATM CC are derived from pitch, yaw and roll rate gyros, coarse and fine sun sensors, a star tracker, a digital computer(ATM DC) and gimbal position resolvers on the CMG units. In addition, manual commands are initiated via a hand controller and control commands are initiated from the astronaut's control panel. Output signals from the unit are the three-axis momentum commands, sent to the appropriate CMG gimbals through the CMG Control Law Resolvers and the rate loop electronics (CMGEA), and the drive currents for the telescopes three-axis gimbal torque motors. There are a) many telemetry signals and other signal outputs sent . , other parts of the PCS system.

The ATM CC operates in five primary modes and a variety of sub-modes which modify the primary modes. Modes, sub-modes and other commands are enabled through a ten-bit digital command system. Decoding of the digital command word places the ATM CC in a particular mode of operation. The primary modes are:

1. Standby mode
2. Monitor, acquisition and gravity gradient momentum dump mode
3. Inertial hold and maneuver mode
4. Experiment pointing mode (telescope operation)
5. RCS momentum dump mode

2.2.1.? Vehicle Control

Vehicle control is accomplished by the electronic processing of vehicle attitude, attitude rate and CMG position (H-vector feedback) signals. The signals may be derived: 1) by the action of the vehicle dynamics on sensor units - sun sensors, star tracker, and rate gyros; 2) from the digital computer (ATM DC) which interprets sensor data and delivers a processed signal; 3) manually from the astronaut's hand controller unit or control panel; and 4) from the CMGs H-feedback (momentum) resolvers.

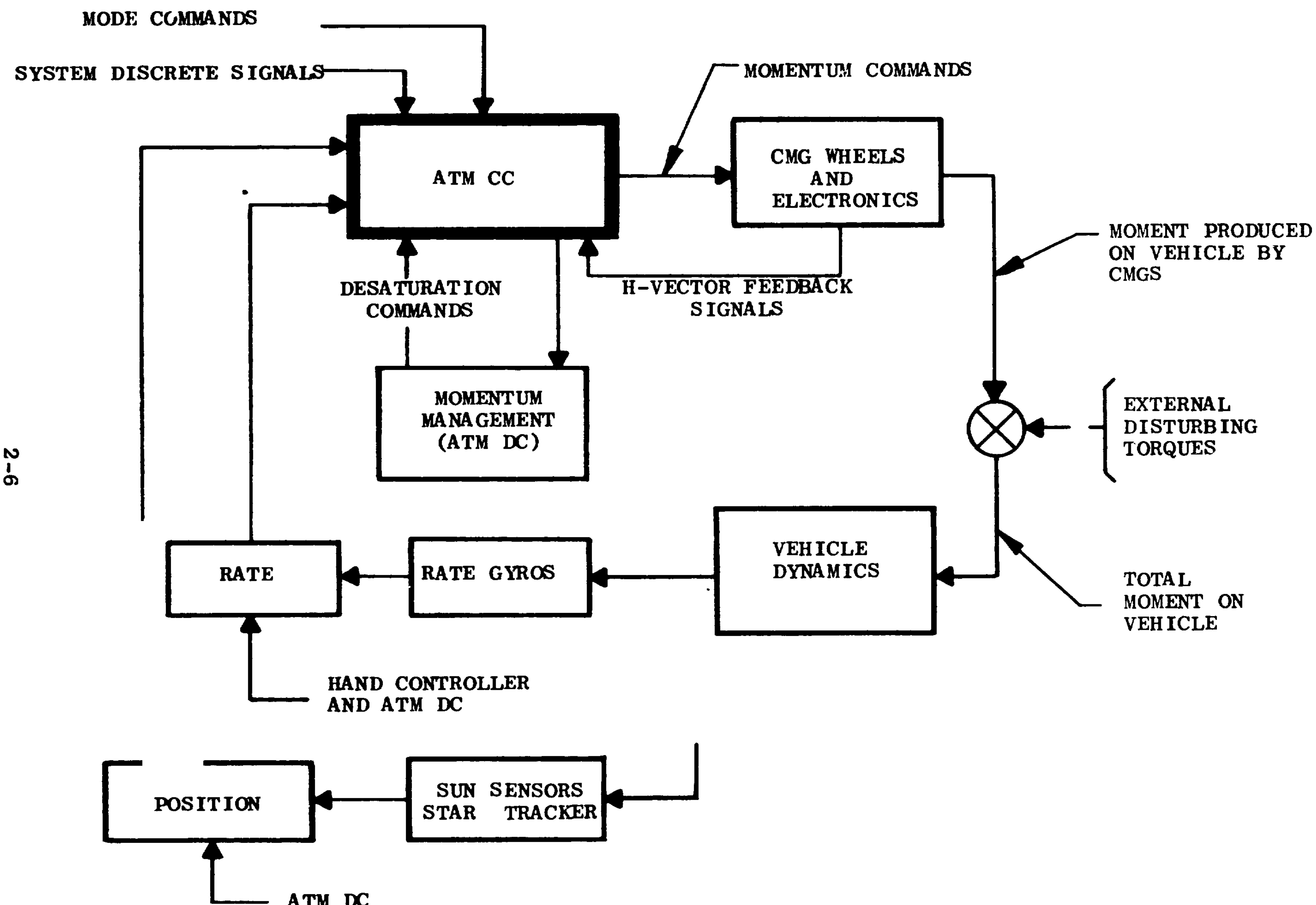
The input signals are processed (amplified, shaped, integrated or differentiated and combined) to produce pitch, yaw and roll torque commands. The torque commands are integrated to produce momentum commands and then compared with the H-vector feedback signals to produce the control error commands which form the ATM CC output signals. These commands are then routed through the CMG electronics and control law resolvers to drive the CMG gimbals. Moving the CMG gimbals moves the CMG total momentum vector and thus produces a moment on the vehicle. This vehicle moment, along with external vehicle torques, creates vehicle motion which is sensed by the sensor units and thus closes the attitude control loops. The hand controller and some other manual commands supplement the sensor information and operate open loop. Momentum control is achieved through the H-vector feedback signals which form a separate closed loop system. A block diagram showing these two control loops and the role of the ATM CC is shown in Figure 2.2.1-1.

The H-vector feedback signals are also used in the ATM DC for desaturation computations. In implementing desaturation (momentum dumping), desaturation signals are fed back into the ATM CC and inserted into the control loops.

2.2.1.2 Telescope Control

Telescope control for the EPS is implemented in one of the primary operating modes. Control is accomplished by the electronic processing of rate and position signals which are amplified and shaped in current amplifiers, power amplified in torquer amplifiers and then fed back to the telescope assembly to drive gimbal torque motors on each of its three axes.

Tracking is accomplished in pitch and yaw by combining signals from the pitch and yaw rate gyros and fine sun sensor (all located on the telescope) and processed through the pitch and yaw motor drive circuitry.



VEHICLE CONTROL FUNCTION OF THE ATM CC

FIGURE 2.2.1-1

Positioning of the telescope is enabled through the hand controller which biases the fine sun sensor (in pitch and yaw). An offset signal is produced in the fine sun sensor which then drives the telescope pitch and yaw gimbals to the new position. Roll position is controlled in open loop fashion from the hand controller which supplies rate commands to drive the roll telescope rate loop directly. These are all sub-modes of operation and the Control Logic routes the signals as required.

2.2.1.3 INPUT SIGNAL CONCEPTS

The input signals to the ATM/CC are selected and routed according to operating mode. Additional details of these input signals are discussed:

1. Rate Gyros - provides inertial reference and rate signals. In normal vehicle maneuvering or inertial hold, signals are obtained from the three rate gyros. Each has two selectable rate outputs. The roll rate gyro is located on the vehicle proper but the pitch and yaw rate gyros are located on the telescope mount. Thus, since telescope gimbal rate resolvers are not provided in pitch and yaw, the telescope (or EPS) must be caged and mechanically locked in its pitch and yaw axes during inertial control of the vehicle.

   In telescope pointing, the yaw and pitch gyro signals are routed through the telescope yaw and pitch control loops. Vehicle yaw and pitch control, during this time, is derived from an acquisition sun sensor located on the vehicle proper.

2. Acqusition Sun Sensor - provides position error signals in pitch and yaw for the vehicle's control loops during (a) normal daylight operation, and (b) operation of the telescope.

3. H-Vector Signals - obtained from the CMG gimbal H-vector resolvers. There are nine signals, three per CMG, resolved into CMG X, Y, and Z components. The ATM/CC recombines these components in the H-vector Summing Amplifiers and then sums them again with each CMG momentum command to form the CMG error momentum commands. They are also sent to the ATM/DC.

4. Orbital Plane Update Signal - provided by the ATM/DC in conjunction with the star tracker. It is furnished by the ATM/DC as a rate command to the roll vehicle loop (Z-Axis), to update the roll position reference.

5. Hand Controller - when enabled by the astronaut, in the appropriate mode, provides rate commands to the vehicle loops.

The hand controller signals can be routed to:

a. drive the three vehicle loops directly for vehicle maneuvers.
b. drive the fine sun sensor (rate command servos) to position the telescope in pitch and yaw.
c. drive the telescope roll rate loop.
d. drive the star tracker in pitch and yaw for a manual star search.

6. Gravity Gradient Momentum Dump Signals - CMG desaturation signals provided by the ATM/DC atuomatically during "night side of orbit" operation. They are fed into the vehicle control loops to re-orient the CMG gimbals.

7. Manual Momentum Dump Signals - are provided as a back-up scneme to the gravity gradient momentum dump signals. They originate from D/A converters in the ATM/CC and are activated by a digital word command from the astronaut's control panel. The word command is processed by the Control Logic section of the ATM/CC.

2.2.1.4 CONTROL LOGIC - accepts and deciphers a 10-bit digital word command. These commands, originating from the astronaut's control panel, (or ground control) implement the system operating modes and sub-modes. The incoming command is first accepted and stored in a storage register. The command is then transfered upon receipt of an "Execute" signal, to a decoding matrix which transforms the command into a discrete signal which appears on one of 300 matrix output command lines. Other discrete signals from the ATM/DC and system sensors are fed into the control logic at this point. All discrete signals are then combined in the Command Matrix by means of logical gating, to perform the following: (1) operate the vehicle and telescope control loop relay switching which connect appropriate input signals and adjust loop gains; (2) supply discrete signals to other parts of the system to either carry out commands, or inform the ATM/DC about the state of the system.

2.2.1.5 ELECTRONIC IMPLEMENTATION

The ATM/CC electronics can be divided into three main groups:

(1) Telescope Control Electronics (Pitch, Yaw, and Roll channels)

(2) Vehicle Control Electronics (Pitch, Yaw, and Roll channels)

(3) Control Logic Electronics

There are also some miscellaneous electronics consisting of telemetry networks and auxilliary circuitry.

The electronics presented here is simply a list of circuit types and quantities to indicate the extent of circuitry in the ATM/CC.

Telescope Control Electronics: (each unit contains its own isolated, regulated DC power supply to operate from +28 VDC)

3 - 800 Hz Demodulators (2 stage amplifier, detector and filter)

5 - Current drivers (3 stage DC amplifier and network)

5 - Torquer Amplifiers (magnetic amplifier and PWM power switch)

Vehicle Control Electronics: (each unit contains its own isolated regulated DC power supply to operate from +28 VDC)

2 - 4.8 KHz Modulators (modulator and 3 stage amplifier)

11 - 4.8 KHz Demodulators (2 stage amplifier, detector and filter)

3 - 800 Hz Demodulators (2 stage amplifier, detector and filter)

3 - Rate Integrators: each contains:

a. DC Amplifier (45V) - (4 stages and power supply)

b. Chopper Amplifier (modulator, 3 stage amplifier, detector, power supply)

c. Network (integrating, scaling, summing)

3 - Torque Command Integrators (4 stage amplifier and network)

2 - Differentiators (4 stage amplifier and network)

3 - Position Summing Amplifiers (2 stage DC amplifier and network)

3 - Summing Amplifiers (2 stage DC amplifier and network)

3 - Momentum Command Drivers (3 stage DC amplifier and network)

3 - H-vector Summing Amplifiers (2 stage amplifier and network)

12 - Bending Mode Filters (4 stage DC amplifier, filter network)

2 - Buffer Amplifiers (Star Tracker Drivers - 3 stage DC amplifier and network)

12 - Telemetry Amplifiers (SN 525 DC amplifiers)

1 - Caging Supply (output is 10 VDC)

<u>Control Logic Electronics</u>

1 - Command Word Interface (10-bit relay logic)

1 - Command Storage Register (10-bit)

1 - Complementary Signal Gating

1 - Decoder Matrix Logic (300 line output)

1 - Command Logic (combines discretes from decoder matrix and system to operate ATM/CC relay drivers)

92 - Relay Driver Circuits (which drive 200 relays) - (approx. quantities)

1 - DC Power Supply (5 VDC for integrated circuit logic chips)

1 - D/A Converter Command Logic (accepts any of 87 discretes from decoder matrix to operate D/A converters)

3 - D/A Converters

1 - Gimbal Stop Logic (combines 12 CMG gimbal stop switch signals to provide signals to Command Matrix)

3 - Null Detectors (45^{o}) - (Gimbal Stop Logic)

Miscellaneous

50 - telemetry networks (resistive dividers) (approx. quan.)

72 - Test isolation resistors (approx. quan.)

1 - 800 Hz Power Amplifier (Class D)

9 - Temperature Sensor Circuits - (telemetry)

3 - Temperature Level Detectors

2.2.1.6 PHYSCIAL DESCRIPTION OF THE ATM/CC

SUMMARY OF CHARACTERISTICS

The ATM/CC is a flat aluminum box of electronics which has the following dimensions and characteristics:

Size: 24" x 40 5/8" x 7 1/4"

Volume: 4.1 cu. ft.

Weight: (a) Empty - 40 lb.

(b) With electronics in place - 125 lb.

Construction: Box

Aluminum: using riveting and dip brazing fabrication techniques

PACKAGING FEATURES

Electronics: packaged as plug-in cards and modules. Total box capacity is as follows:

1. Section 1: 120 - 4x5 cards - control loop electronics, relays and drivers
2. Section 2: 5 - channels for Torquer Amplifiers (4" x 5" x 5.5")
3. Section 3: Control Logic Decoder: 7.5" x 7.5" x 5" (12 cards)
4. Section 4: Control Logic: 7.5" x 7.5" x 5" (13 cards)
5. Section 5: 8 - 5x7 cards
   a. Logic DC Power Supply
   b. Command Word Interface
   c. Caging Power Supply
   d. Terminal Board and Diodes

Spare card spaces in Section 1 consisted of 18, 4 x 5 cards.

Amplifiers comprise the 4 x 5 plug-in cards. Many of the associated networks are packaged as "piggy-back" cards which plug onto the amplifier cards.

All cards and modules are plug-in and their associated connectors are interwired in a harness which also includes the input/output connectors.

There are 16 input/output connectors which go to a transfer box. Connections are made to the 3 CMGEA's, 3 CMGIA's, telescope equipment, other sensors and resolvers, ATM/DC, test terminals, telemetry, and power.

POWER CONSUMPTION

The following is an estimated power consumption breakdown of the various cards and modules of the ATM CC. Input power to the ATM CC is from the +28 VDC line. (There are also 4.8 KHz and 800 Hz excitation inputs). A summary is given below:

ATM/CC SECTION		QUIESCENT POWER (WATTS)	NOMINAL POWER (WATTS)	MAXIMUM POWER (WATTS)
Pitch Vehicle Loop	30 Cards	19.8	(20.2)	24.3
Yaw Vehicle Loop	30 Cards	19.5	(19.9)	24.0
Roll Vehicle Loop	24 Cards	16.9	(17.3)	21.0
Pitch Telescope Loop	4 Cards 2 Torq. Amps	11.5	36.9	175.1
Yaw Telescope Loop	3 1/2 Cards 2 Torq. Amps	11.5	36.9	175.1
Roll Telescope Loop	2 1/2 Cards 2 Torq. Amps	6.5	18.2	83.4
Control Logic	3 5x7 Cards 2 7.5x7.5 sect.	6.4	(7.4)	8.6
TOTAL ATM/CC - (WATTS)		92.1	(156.8)	508

2.2.2 Experiment Pointing Electronics Assembly (EPEA)

2.2.2.1 Introduction

The dual redundant Experiment Pointing Electronics Assembly (EPEA) contains the electronic circuits for amplifying, and mixing the outputs of the spar-mounted sensors to obtain error signals to drive the Experiment Pointing and Control (EPC) Subsystem actuators (DC torque motors). Provisions are included to allow internal switching of sensor outputs and/or electronic subsystems for redundancy management. The electronic subsystems are divided into 14 channels which can be switched from either ground command via the DCS or by astronaut via the DAS.

Interface circuitry between the Manual Pointing Controller (MPC) and the Fine Sun Sensor (FSS) and Star Tracker (ST) is also included in the EPEA. Output rate commands from the MPC are conditioned to drive either the wedge assemblies in the FSS for offset pointing of the experiment package or the Star Tracker gimbals (manual mode). Rate commands from either rate switches on the C and D Console or the external EVA Rotation Control Panel may be applied to the EPEA to drive the EPC roll axis.

Caging of the EPC is accomplished with orbital locks for the pitch and yaw axes and by a brake mechanism for the roll axis. Mode logic controls the caging commands.

2.2.2.2 General Description

The EPEA is a multipurpose analog assembly that processes sensor signals and provides commands to the experiment pointing system actuators. The EPEA also contains command logic necessary for mode and submode switching via the command system. Discrete commands are sent to the EPEA from the Apollo Telescope Mount Digital Computer (ATMDC). Signals are also received from spar-mounted rate gyros, the Fine Sun Sensor (FSS), the Control and Display (C and D) Console, and from the EVA Rotation Control Panel.

There are several functions provided by the EPEA. It processes rate and position signals to generate drive actuator signals for the pitch and yaw axes of the EPC Subsystem; processes input rate commands from the C and D Console or the EVA Rotation Control Panel and provides rate commands to the roll actuator; it accepts and processes commands from the Manual Pointing Controller (MPC) and provides pitch and yaw commands which can be steered to either the FSS or the Star Tracker in the manned mode; it accepts DC (unmodulated) command signals from the ATMDC to drive the FSS in the unmanned mode or the Star Tracker (ground test only); and processes the cage and uncage commands to the pitch and yaw orbital locks of the EPC/RPM gimbal system.

Figure 2.2.2-1 is a functional block diagram of the EPEA showing the various signal processing channels. The figure shows only functional paths through each channel, however, redundant paths do exist for each processed signal.

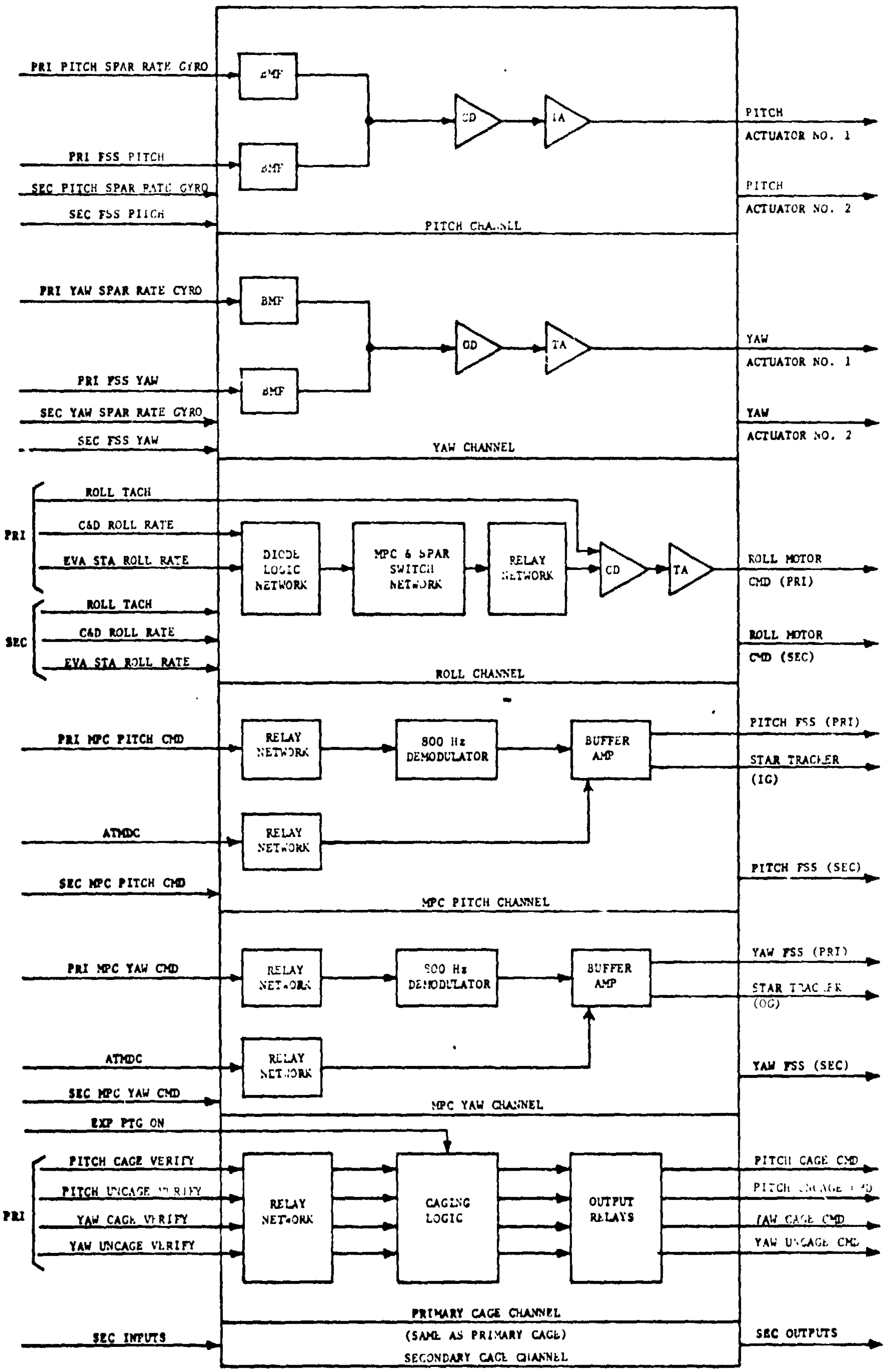


FIGURE 2.2.2-1 EPEA Single Channel Block Diagram

2.2.2.3 EPEA Operation

The EPEA accepts rate and attitude error signals from the spar-mounted Rate Gyro Packages (RGPs) and the Fine Sun Sensor (FSS), respectively. Signals are also sent to the EPEA from the Control and Display (C and D) Console, EVA Rotation Control Panel, and from the ATMDC.

The pitch and yaw channels accept position signals from the FSS and rate signals from the rate gyros. These signals are amplified and shaped to supply output currents to drive the EPC pitch and yaw actuators.

The roll channel accepts a fixed rate command from the C and D Console or EVA station which is processed to drive the EPC roll actuator.

The MPC pitch and yaw channels accept signals from the C and D Console to drive either the FSS wedges or the ST gimbals when operating in the manned mode, and accept signals from the ATMDC to drive the ST during ground test operations and the FSS in the unmanned mode.

Pitch and yaw cage/uncage loops are provided to allow on-orbit locking or unlocking of the canister/experiment package. The canister is locked in the zero position in both axes during all APCS primary modes, except the Experiment Pointing Mode. In this mode, the canister is unlocked to allow solar experiments to be performed.

2.2.2.3.1 X (Pitch) Loop

Figure 2.2.2-2 is a functional block diagram of the X

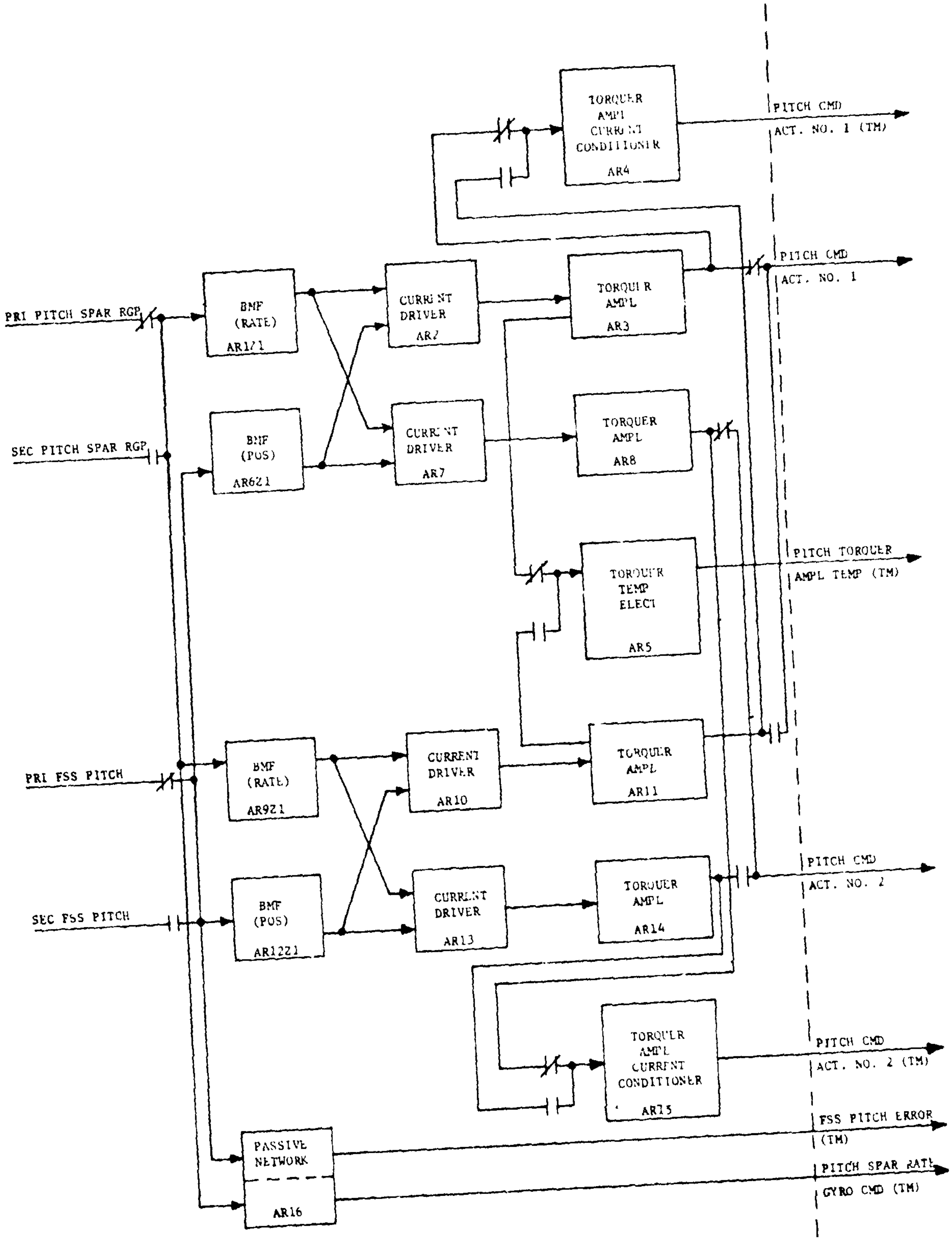


Figure 2.2.2-2 Pitch Channel Block Diagram

(Pitch) Loop. Inputs to the loop are in the form of rate and attitude error signals from a spar-mounted primary or secondary rate gyro and from a primary or secondary FSS. The rate and position input signals are fed through a relay network to passive networks and to different bending mode filters (BMFs). Outputs from the passive networks are transmitted by telemetry to ground, while the outputs from the BMFs are fed to the summing amplifiers where the rate and position signals are summed, amplified, and conditioned to drive, simultaneously, two identical torquer amplifiers. The torquer amplifiers provide sufficient current output to drive the torquer motors.

Redundant operation is provided through the use of two torquers, mounted on the axial supports; each is fed by a separate current-limited torquer amplifier. Each torquer amplifier is driven by separate current drivers. However, each front end of the current driver, i.e., the summing amplifier, can be fed from either the primary or secondary sensor signals via the BMFs. Figure 2.2.2-2 illustrates the redundant paths.

Output current supplied to the pitch torquers is also scaled by the Torquer Amplifier Current Conditioner and sent out to the telemetry networks. Torquer amplifier temperature is also measured, processed by a temperature conditioner, and sent out to the telemetry network.

Each unit in the pitch channel is discussed in the following paragraphs.

2.2.2.3.1.1 Bending Mode Filters (AR1Z1, AR6Z1, AR9Z1, AR12Z1)

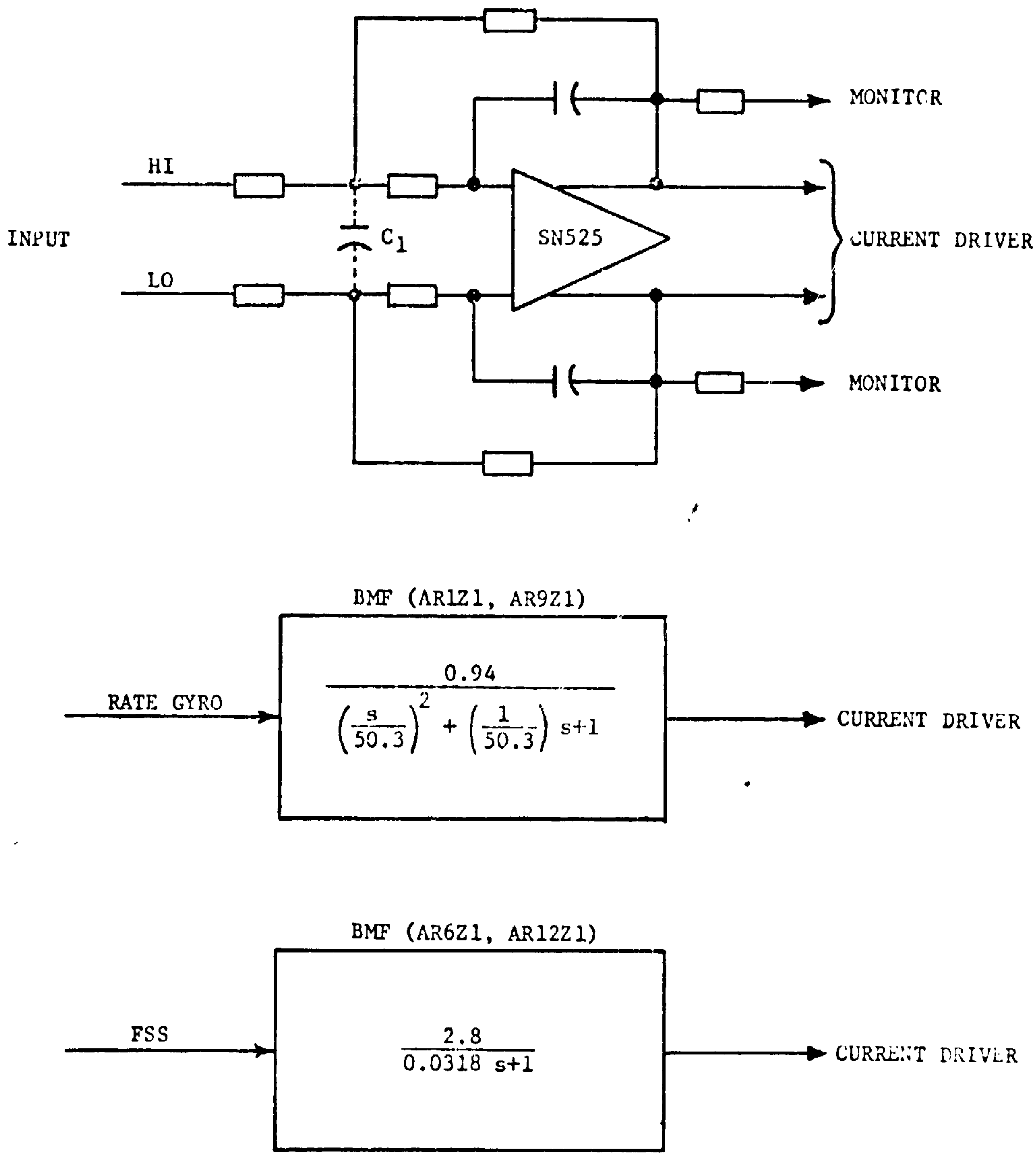
The vehicle bending modes, caused by the structural elasticity of the vehicle, may couple with other parts of the vehicle, to produce instability and are therefore filtered out of the signal. The filter is a low-pass type consisting of a DC amplifier with appropriate RC networks to filter the higher frequencies. Outputs from the respective filters are fed to summing amplifiers where the rate and position signals are summed to form the torquer driving signal.

Figure 2.2.2-3 shows the two types of filters used in the X (pitch) channel. When C_1 is connected as shown, the filter has a second-order transfer function and is used to filter the input from the rate gyros. When C_1 is not connected, the filter is a first-order type and is used to filter the input from the FSS. The transfer functions and values used are shown on the figure.

2.2.2.3.1.2 Current Driver (AR2, AR7, AR10, AR13

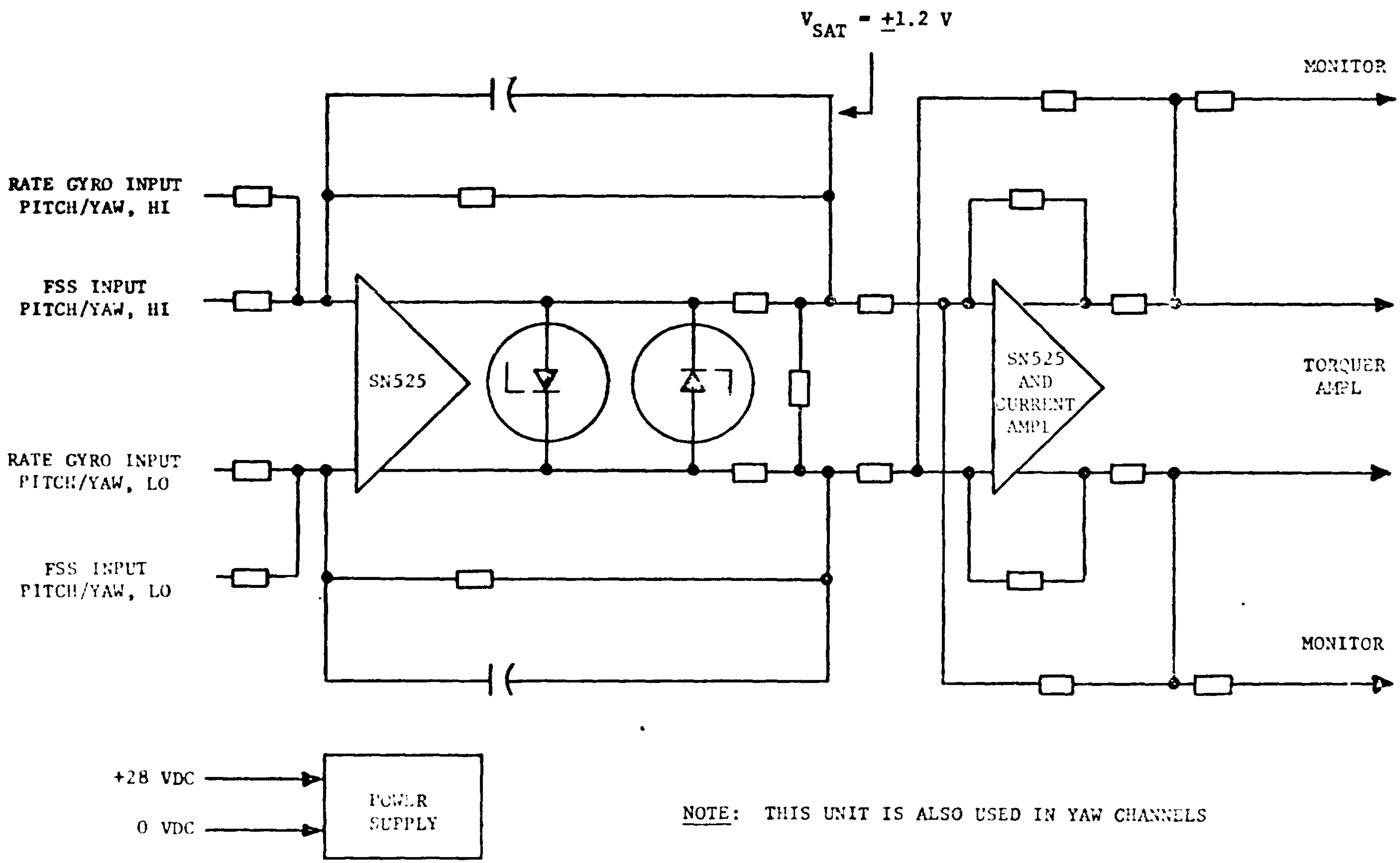
The first amplifier section (see Figure 2.2.2-4) sums the rate and position signal outputs from their respective bending mode filters. The first amplifier is voltage limited to ± 1.2 volts, maximum, and drives the second amplifier section, which provides a current drive for the Torquer Amplifier.

A DC-to-DC converter supplies the power for the circuitry, which consists of two SN525 differential amplifiers for summing and gain, and a complementary



NOTE: RATE GYRO BMF INCLUDES C1
FSS BMF DOES NOT INCLUDE C1

Figure 2.2.2-3 **Bending Mode Filters (Spar Pitch and Yaw)**



NOTE: THIS UNIT IS ALSO USED IN YAW CHANNELS

Figure 2.2.2-4 Current Driver

transistor current amplifier.

2.2.2.3.1.3 Torquer Amplifier (AR3, AR8, AR11, AR14)

A torquer (power) amplifier, shown in block diagram form in Figure 2.2.2-5, provides the current to drive the EPC gimbal actuators. The circuit employs an inverter, a magnetic amplifier, and a power bridge.

The inverter section employs a transformer and four transistors connected in Darlington pairs. The circuit is self oscillating at approximately 3.9 KHz. The oscillator drivers current through the transformer's primary windings. Two of the secondary windings are rectified and filtered to provide a +80 VDC power supply and a ±5 VDC bias supply. The remaining output windings of the transformer are rectified to provide pulses to the magnetic amplifier. The magnetic amplifier is actually two magnetic amplifiers (each with two cores) which drive two sides of the output power bridge. The magnetic amplifier bias windings control the duty cycle of the switching pulses under zero input conditions. The input signal winding controls the symmetry of the switching pulses to provide the required current output. The two halves of the power H-bridge switch alternately at approximately 7.8 KHz (double the inverter frequency), following the magnetic amplifier pulse-width-modulated pulses. Both voltage and current feedback around both magnetic amplifiers couple the load current back to the input to stabilize current gain. LC circuits at the input and out-

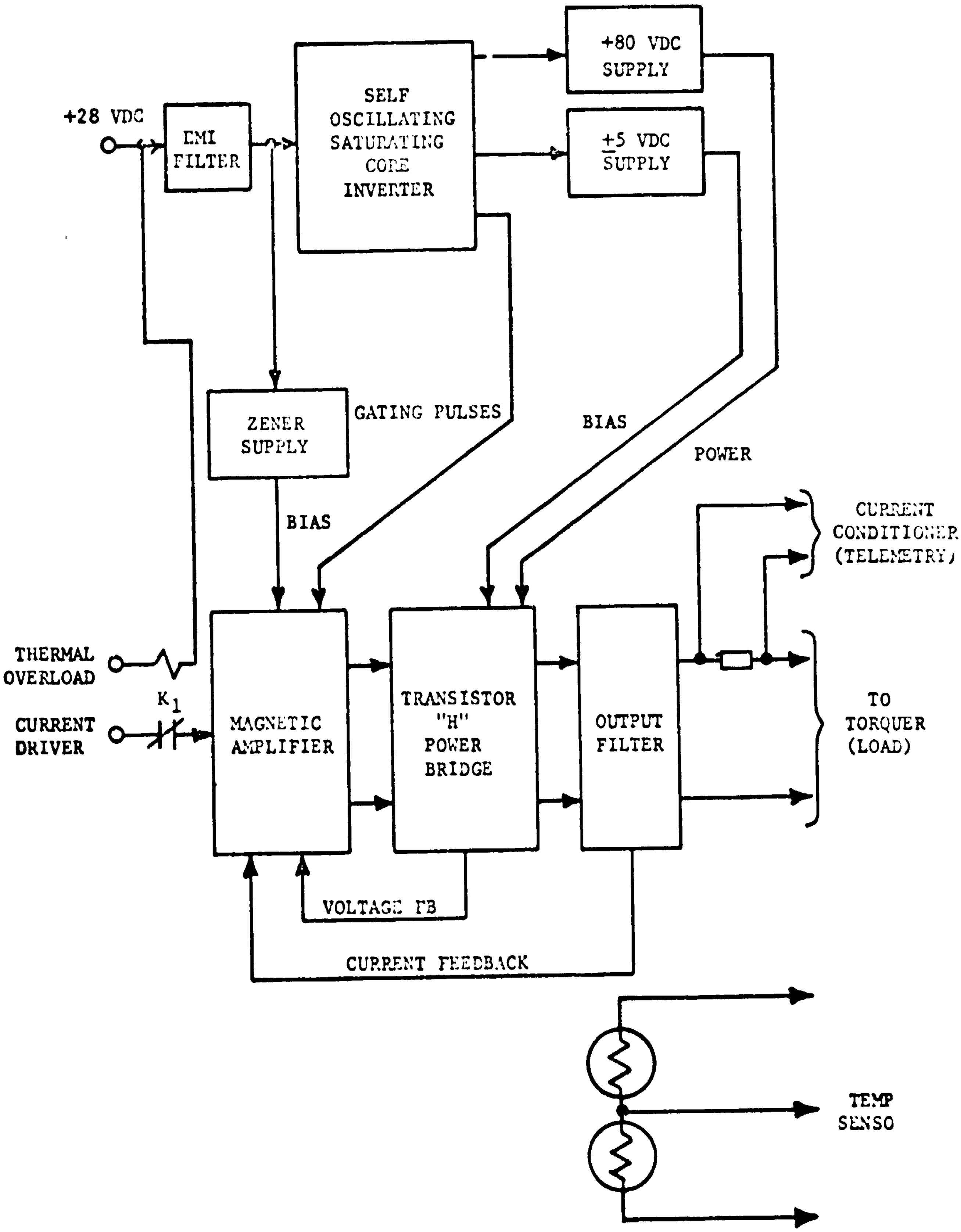


Figure 2.2.2-5 **Torquer Amplifier Block Diagram**

put of the bridge provide EMI filtering. Two temperature sensing thermistors are located in the power-bridge heat-sink to provide temperature information to the telemetry subsystem.

2.2.2.3.1.4 Temperature Conditioner and Detector (AR5)

The Temperature Conditioner accepts signals only from thermistor sensors located in torquer amplifiers, AR3 and AR11, and prepares the signal to be sent down by telemetry. The electronics are shown in Figure 2.2.2-6. The circuit basically consists of a resistor divider and amplifier section which converts the thermistor value to a level-shifted voltage signal which is then buffered. The buffered temperature signal is sent to the telemetry subsystem and is also fed to a level detector which detects when the temperature signal exceeds a predetermined level. When this occurs, a relay circuit is activated which causes a voltage discrete signal to be sent to ground via telemetry.

2.2.2.3.1.5 Torquer Current Conditioner (AR4, AR15)

There are two units (see Figure 2.2.2-7) located in the X Channel. The input of each Torquer Current Conditioner can be switched to measure the output of the primary or secondary torquer amplifiers 1 and 2, respectively. The conditioner receives a differential voltage proportional to the torquer current, derived from the series sensing resistor in the torquer amplifier's output. Gating pulses to the magnetic amplifier with a differential

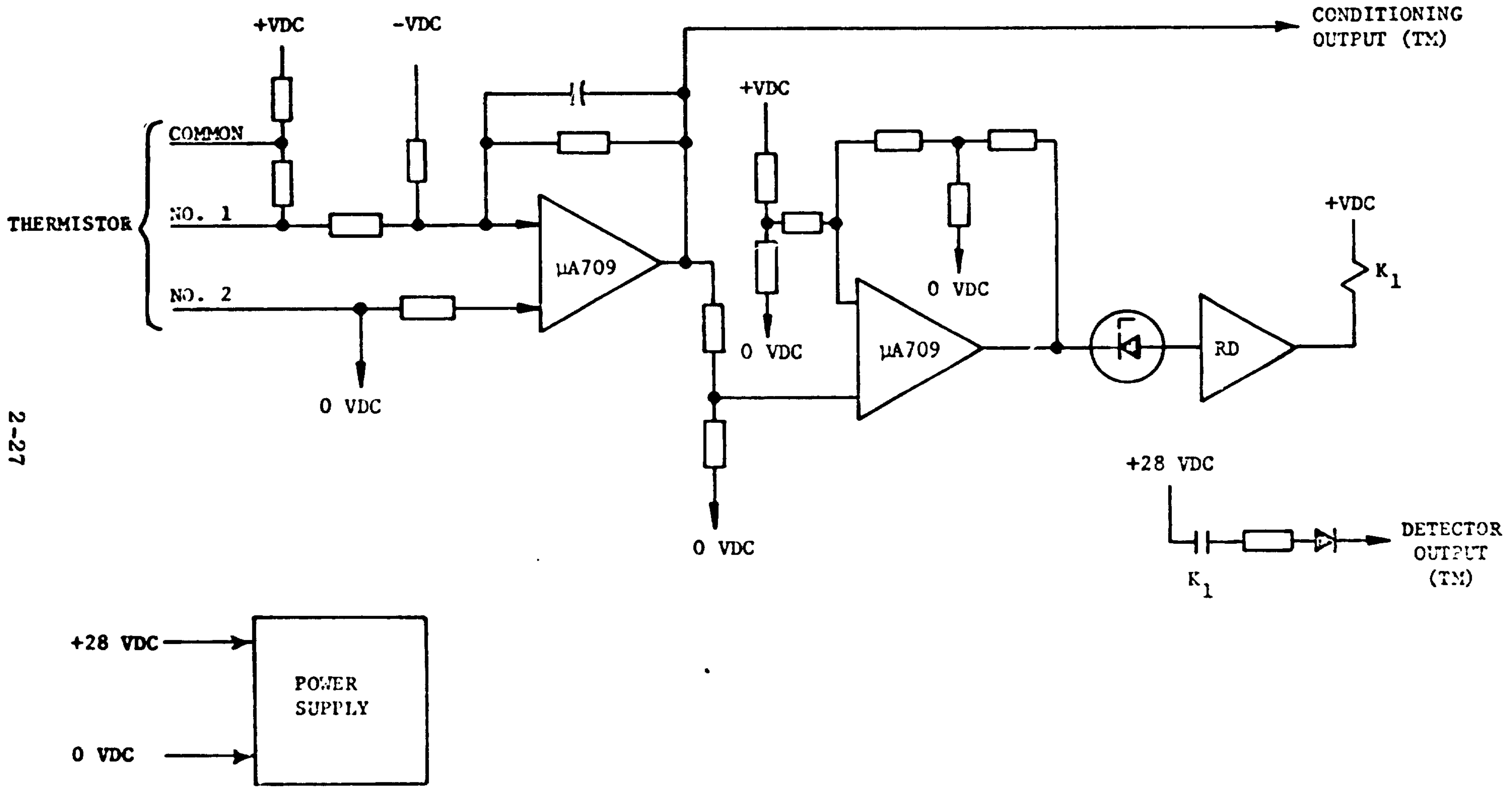


Figure 2.2.2-6. Temperature Conditioner and Detector

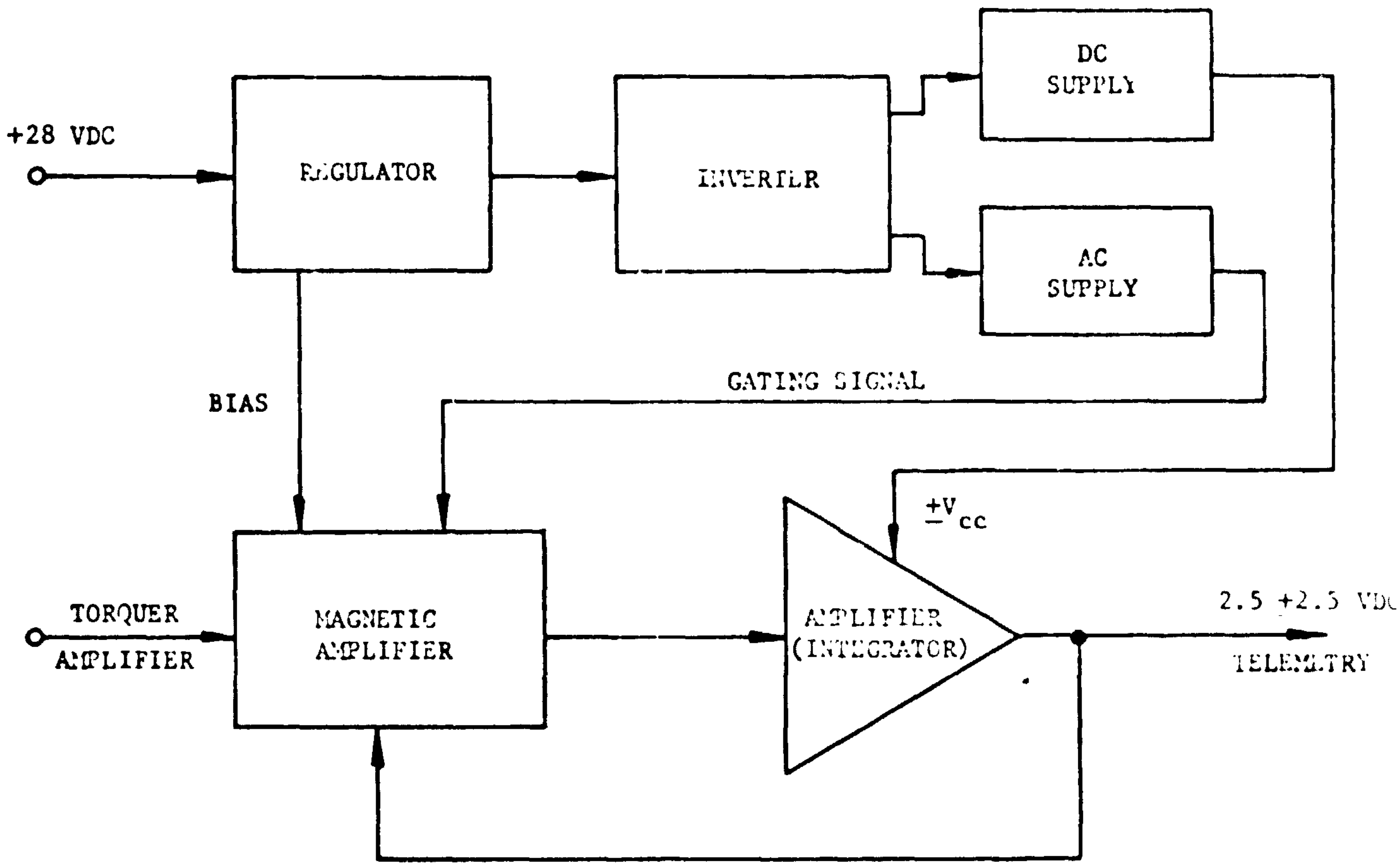


Figure 2.2.2-7 Torquer Current Conditioner Block Diagram

output. Gating pulses to the magnetic amplifier are supplied by a winding on the flux oscillator of the card's DC power supply. The magnetic amplifier's output is a series of pulses, either positive or negative, whose DC value is proportional to the pulse's energy content. The second stage is a high gain integrator which sums these pulses. A DC biasing arrangement on the magnetic amplifier's input provides a +2.5 VDC output with no signal input (i.e., no torquer current). The measured current value, then rides on a +2.5 VDC bias and is scaled linearly to 0.5 volts per ampere.

The magnetic amplifier's input isolation feature isolates the high voltages present in the torquer drive; the sensing resistor is small (0.5 ohms) and the H-bridge switches +80 VDC, alternating the polarity, at approximately an 8 KHz rate.

2.2.2.3.2 Y (Yaw) Loop

The Y loop as shown in Figure 2.2.2-8 is identical to the X loop and therefore the discussion of the pitch loop given in 2.2.2.3.1 is applicable to the yaw loop.

2.2.2.3.2.1 Bending Mode Filters (AR17Z1, AR25Z1, AR22Z1, AR28Z1)

See 2.2.2.3.1.1.

2.2.2.3.2.2 Current Drivers (AR18, AR23, AR26, AR29)

See 2.2.2.3.1.2.

2.2.2.3.2.3 Torquer Amplifiers (AR19, AR24, AR27, AR30)

See 2.2.2.3.1.3.

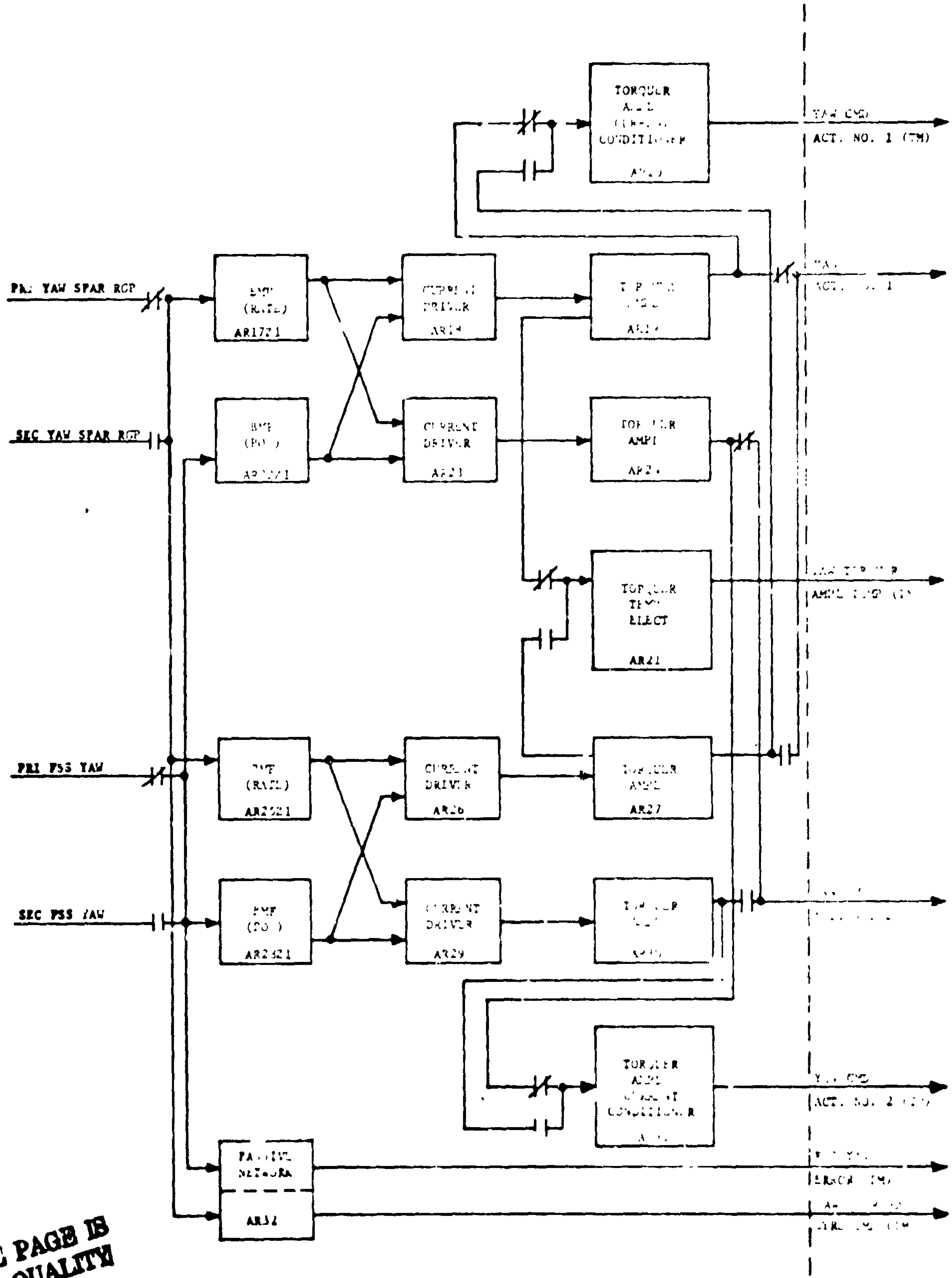


Figure 2.2.2-8 Yaw Channel Block Diagram

2.2.2.3.2.4 Temperature Conditioner and Detector (AR21)
See 2.2.2.3.1.4.

2.2.2.3.2.5 Torquer Current Conditioner (AR20, AR31)
See 2.2.2.3.1.5.

2.2.2.3.3 Z (Roll) Loop

A block diagram of the roll loop is shown in Figure 2.2.2-9. The roll loop is operated in an open loop fashion with respect to attitude and closed loop with respect to rate. A tachometer is used for rate damping. The roll rate commands are initiated manually, either from the C and D Console switches or from the EVA Rotation Control Panel switches. The input commands pass through a diode logic network to the MPC and Spar Switching Network, where a command voltage is generated, corresponding to the rate and polarity selected by the logic network, and is applied to the current driver. Here the signal is summed with the signal from the Roll Positioning Mechanism (RPM) tachometer. The Current Driver then provides a current driving signal for the Torquer Amplifier which drives the roll actuator.

Output voltages of ± 4.2, ± 2.1, ± 0.42, and ± 0.21 VDC from the MPC and Spar Switching Network which correspond to spar roll rates of ± 7, ± 3.5, ± 0.7, and ± 0.35 degrees per second, respectively, can be commanded from the C and D Console. Spar roll rates of ± 7 and ± 0.7 degrees per second can be commanded from the EVA station.

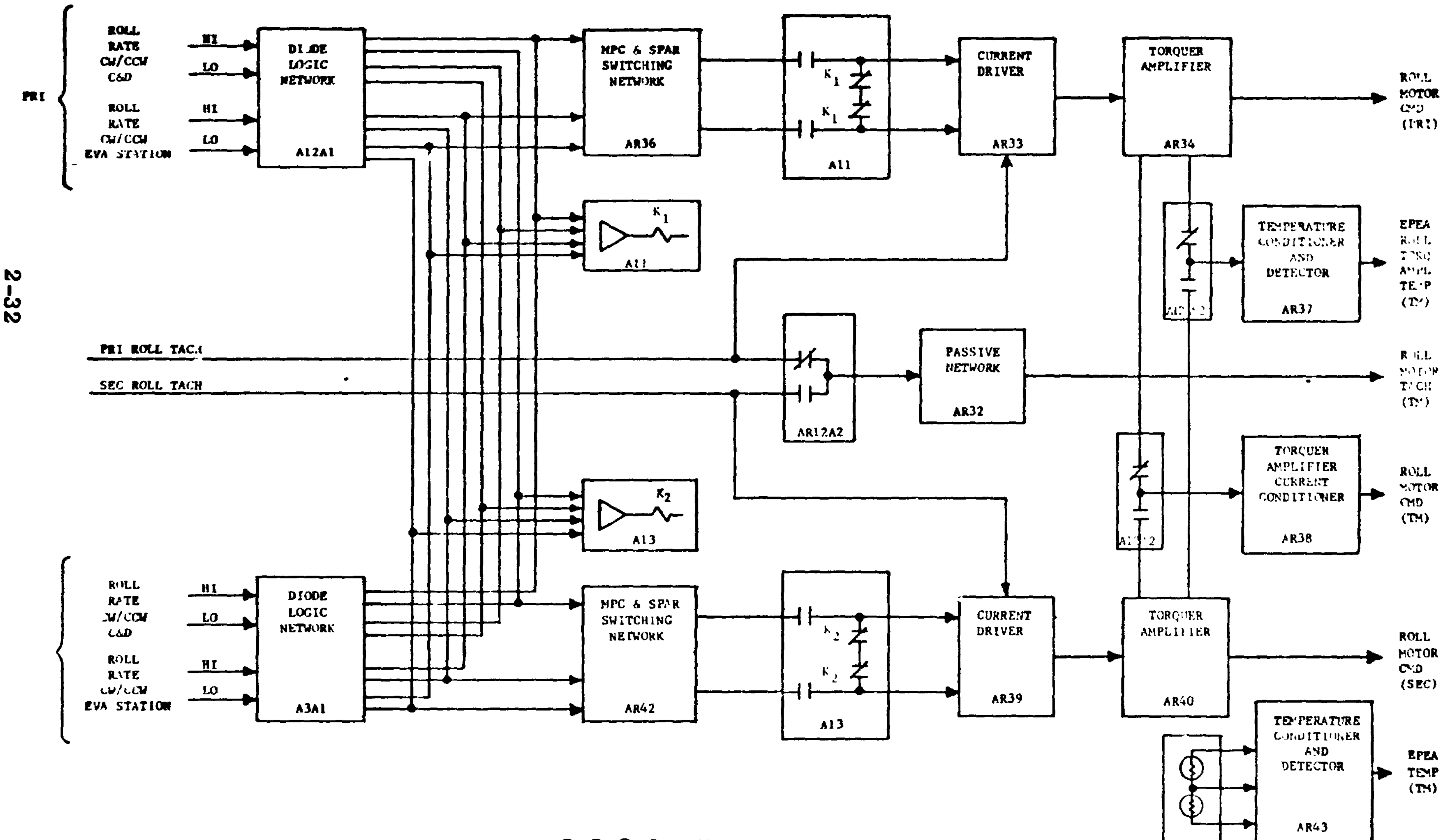


Figure 2.2.2-9 Roll Channel Block Diagram

Once the spar is positioned, the RPM will hold the location until a repositioning command is received.

2.2.2.3.3.1 Roll Rate Logic (A3A1, A12A1)

There are two identical roll rate logic units located in the Z channel as shown in Figure 2.2.2-10. Each channel processes both the primary and secondary command signals. The outputs of the two logic units are connected in parallel so that a redundant path through the diode logic is provided for both the primary and secondary inputs.

The unit accepts +28 VDC discrete signals on command from the C and D Console and/or the EVA station. Selection of a rate command of desired rate and rotational direction (providing the roll channel is enabled) will result in the EPC spar being driven at the appropriate roll rate in the appropriate direction.

2.2.2.3.3.2 MPC and Spar Switching Network (AR36, AR42)

There are two of these units (see Figure 2.2.2-11) in the Z (roll) loop. The input to each unit may be activated by either primary or secondary rate commands, however, the output of each unit drives the primary and secondary channels, respectively.

Each switching network consists of three relays and drivers, a DC reference supply, and a varaible gain DC amplifier. The relays are activated by the diode logic circuit (described in 2.2.2.3.3.1). The DC signal is provided by a Zener diode and then fed to

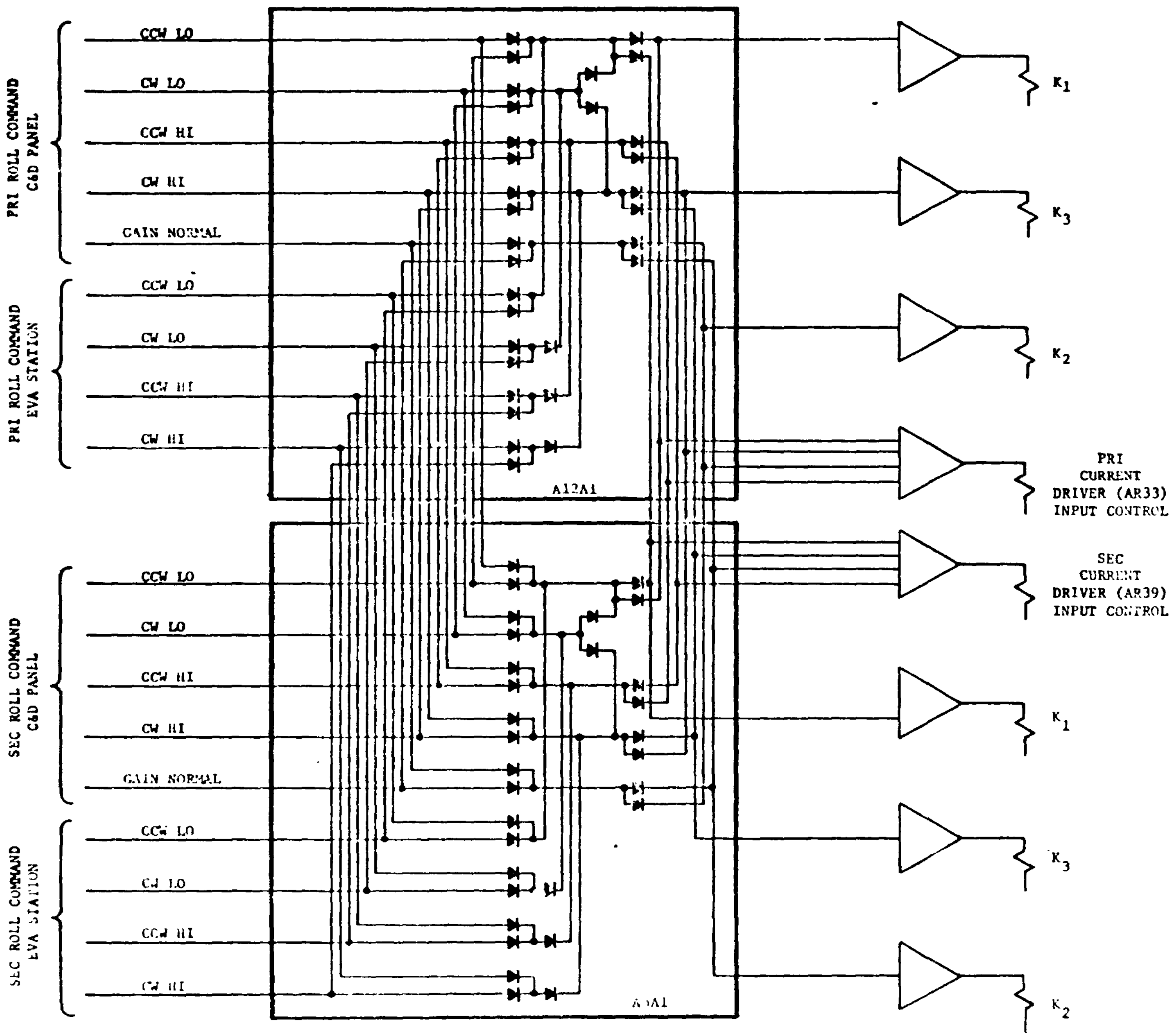
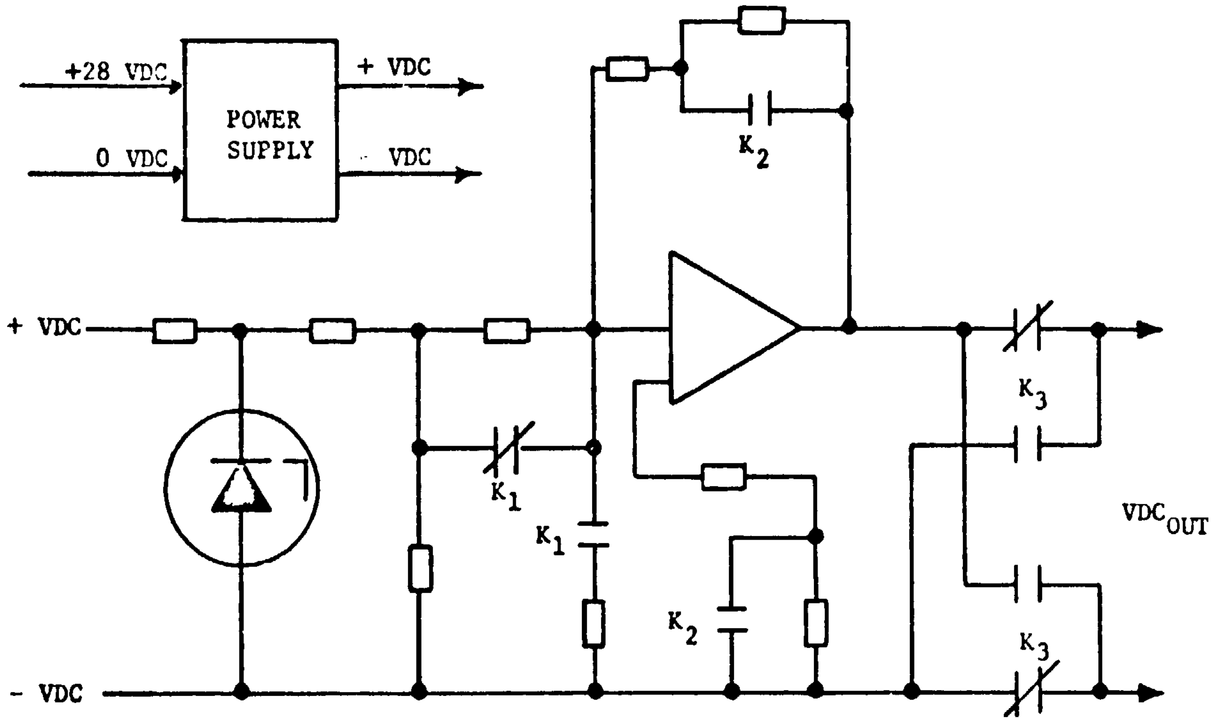
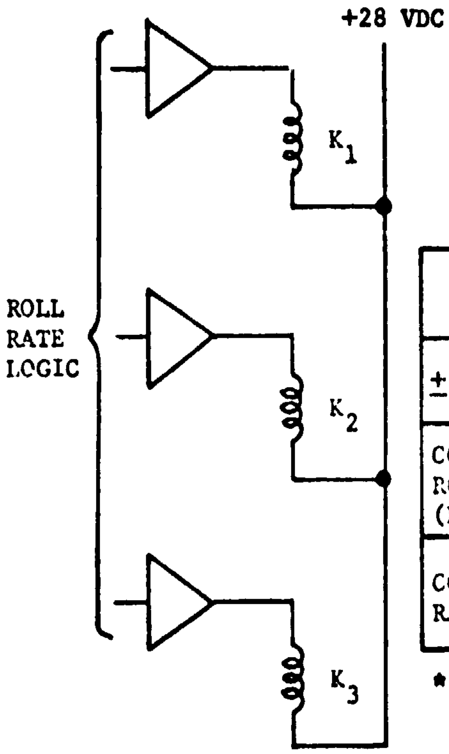


Figure 2.2.2-10. Roll Rate Logic





RELAY ENERGIZED	-	K_2	K_1	K_1, K_2
± VDC_{OUT}*	4.2	2.1	0.42	0.21
CORRESPONDING ROLL RATE (DEG/SEC)	7	3.5	0.7	0.35
CORRESPONDING RATE CONDS	HI	HI GAIN NORM	LO	LO GAIN NORM

* CCW = + VDC (K_3 unenergized)
CW = - VDC (K_3 energized)

Figure 2.2.2-11. MPC/Spar Switching Network a DC operational amplifier (SN525) whose gain is changed by changing its input and feedback resistor values. This is accomplished with relay switching. A Zener regulated DC voltage applied to the amplifier input network provides the input signal.

When a High Roll Rate Command is received, the output of the unit is +4.2 VDC which corresponds to a canister roll rate of 7 degrees per second. With a Gain Normal Command, K_2 is energized, giving an output command of +2.1 VDC corresponding to 3.5 degrees per second. Each of these rates is reduced by a factor of 10 when a Low Roll Rate Command energizes K_1.

Relay K_3 is used to reverse the output signal.

2.2.2.3.3.3 Current Driver (AR33, AR39)

2.2.2.3.3.4 Torquer Amplifier (AR34, AR40)
See 2.2.2.3.1.3

2.2.2.3.3.5 Temperature Conditioner and Detector (AR37, AR43)
See 2.2.2.3.1.4.

2.2.2.3.3.6 Torquer Current Conditioner (AR38)
See 2.2.2.3.1.5

2.2.2.3.3.7 Relay Network (A11, A13)
This is an amplifier driven network (see Figure 2.2.2-12) which connects the output of the MPC and Spar Switching network to the input of the current

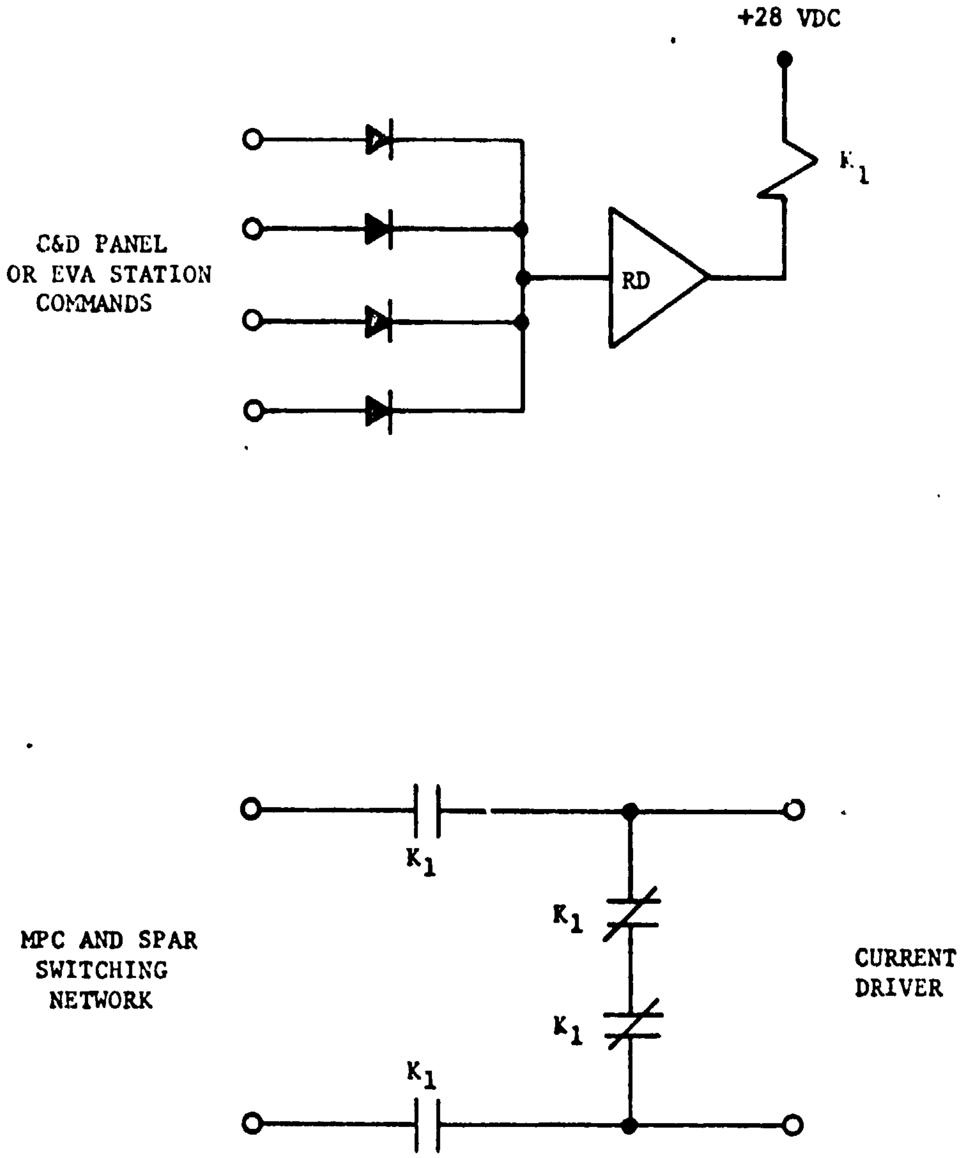


Figure 2.2.2-12. Relay Network

driver any time there is an input command to the Z channel.

2.2.2.3.4 Manual Pointing Control (MPC) Pitch/Yaw Axis

The MPC channel provides the drive signals to position the FSS wedges or the Star Tracker gimbals as shown in Figures 2.2.2-13 and 2.2.2-14. MPC command signals are initiated via the MPC unit located on the C and D Console during the manned mode or from the ATMDC when operating in the unmanned mode (FSS wedges only). The input commands, modulated 800 Hz signals, pass through relay networks and are applied to dual 800 Hz demodulators. After demodulation, the signals are buffered and applied to the drive motors of the FSS wedges or the Star Tracker gimbal torquers via additional relay networks.

The pitch channel controls the inner gimbal of the Star Tracker or moves the FSS wedges in an up-down direction. The yaw channel controls the outer gimbal of the Star Tracker or moves the FSS wedges in a left-right direction. The direction of motion of the FSS wedges is with respect to the TV display (C and D Console) of the NRL-B experiment.

2.2.2.3.4.1 Dual 800 Hz Demodulators (AR44, AR46)

This unit (see Figure 2.2.2-15) accepts an amplitude modulated 800 Hz signal from the MPC and demodulates it, producing a DC output. The unit consists of a DC-to-DC converter, and two identical demodulation channels. Each modulation channel

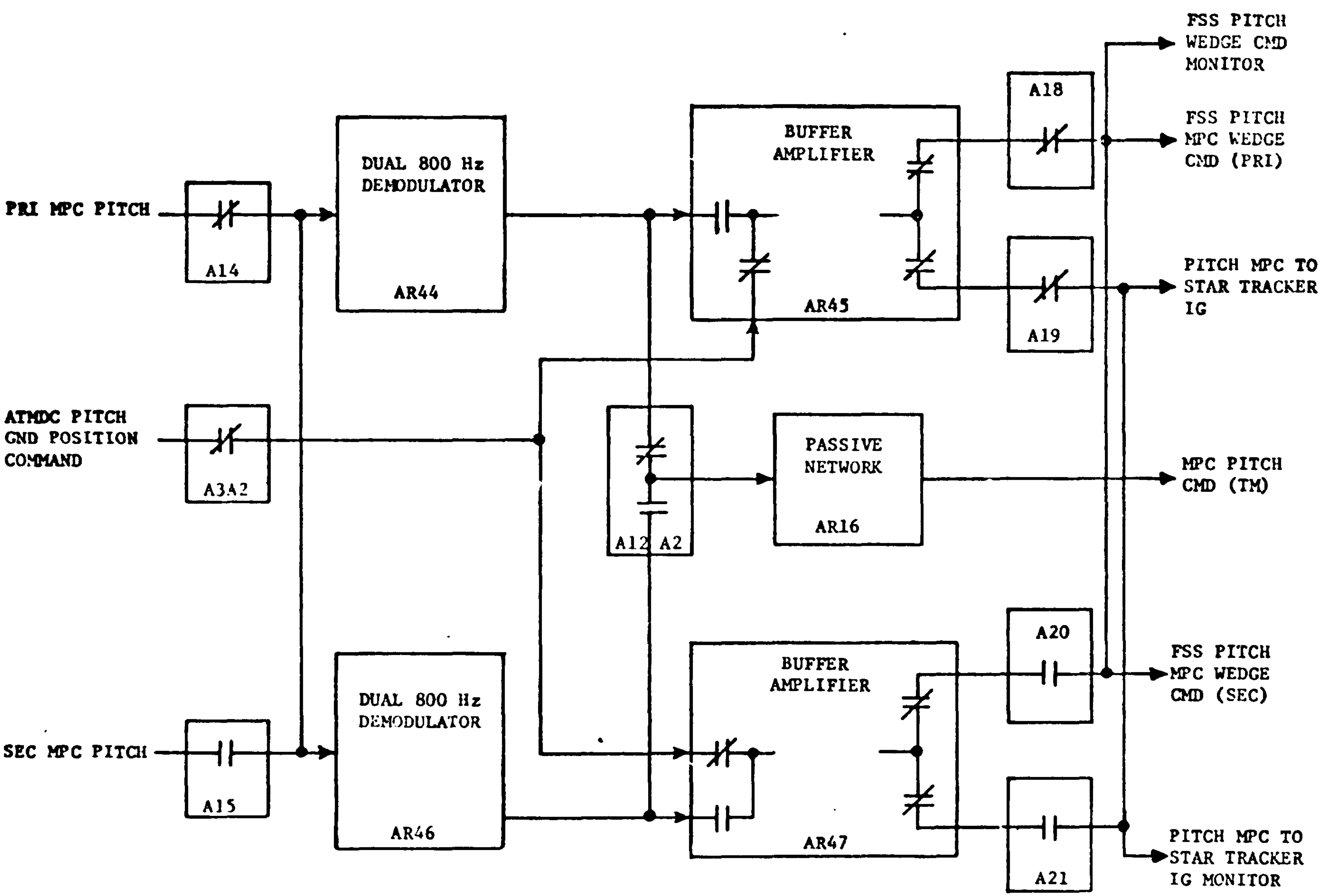


Figure 2.2.2-13 MPC Pitch Channel

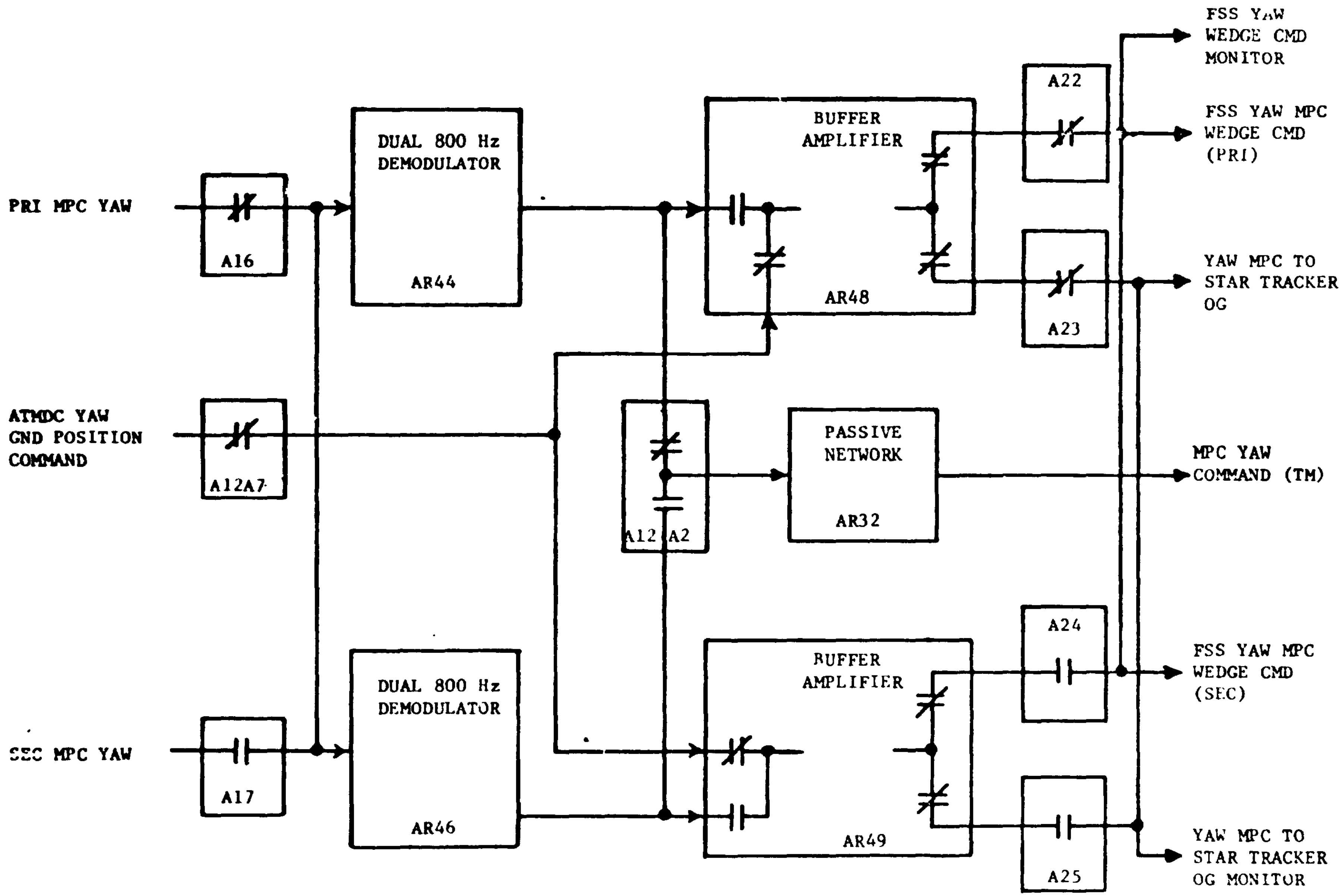


Figure 2.2.2-14 MPC Yaw Channel

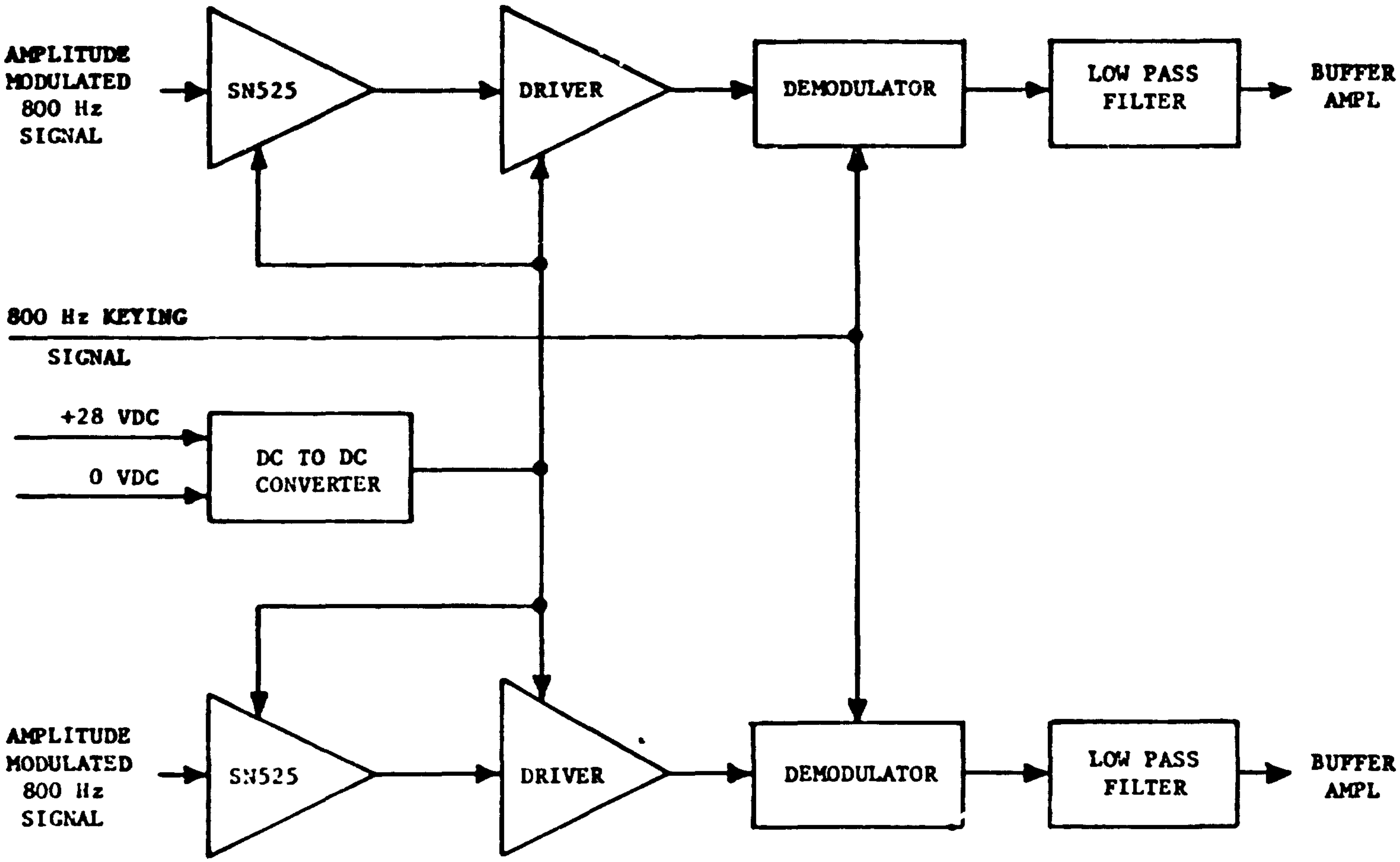


Figure 2.2.2-15. Dual 800 Hz Demodulator

consists of an SN525 amplifier with a dual complementary transistor stage which drives the demodulator section. Here the signal is chopped, in phase, with the 800 Hz keying signal, demodulated, and passed through a low-pass filter to remove the residual demodulator noise.

2.2.2.3.4.2 Buffer Amplifier (AR45, AR47, AR48, AR49)

There are two buffer amplifiers used in each MPC pitch and yaw channel. The four amplifiers are identical; a typical one is shown in Figure 2.2.2-16. The amplifier module contains a power supply, relay drivers, and relays, and an operational amplifier with a gain of 2. The relays are driven by discrete input commands which select the desired input path (from the demodulator or ATMDC) and output path (to the Star Tracker or FSS).

2.2.2.3.5 Orbital Caging

Figure 2.2.2-17 shows the block diagram of the caging channels. Whenever the APCS is not in the Experiment Pointing (EXP PTG) mode, the spar will automatically be returned to the pitch and yaw zero positions and locked. Upon entering the Experiment Pointing mode, the spar is automatically unlocked.

The orbital caging channels in the EPEA provide a primary and secondary system for both the pitch and yaw orbital locks, along with the necessary relay networks to do the required switching. The primary pitch and yaw caging logic is contained in

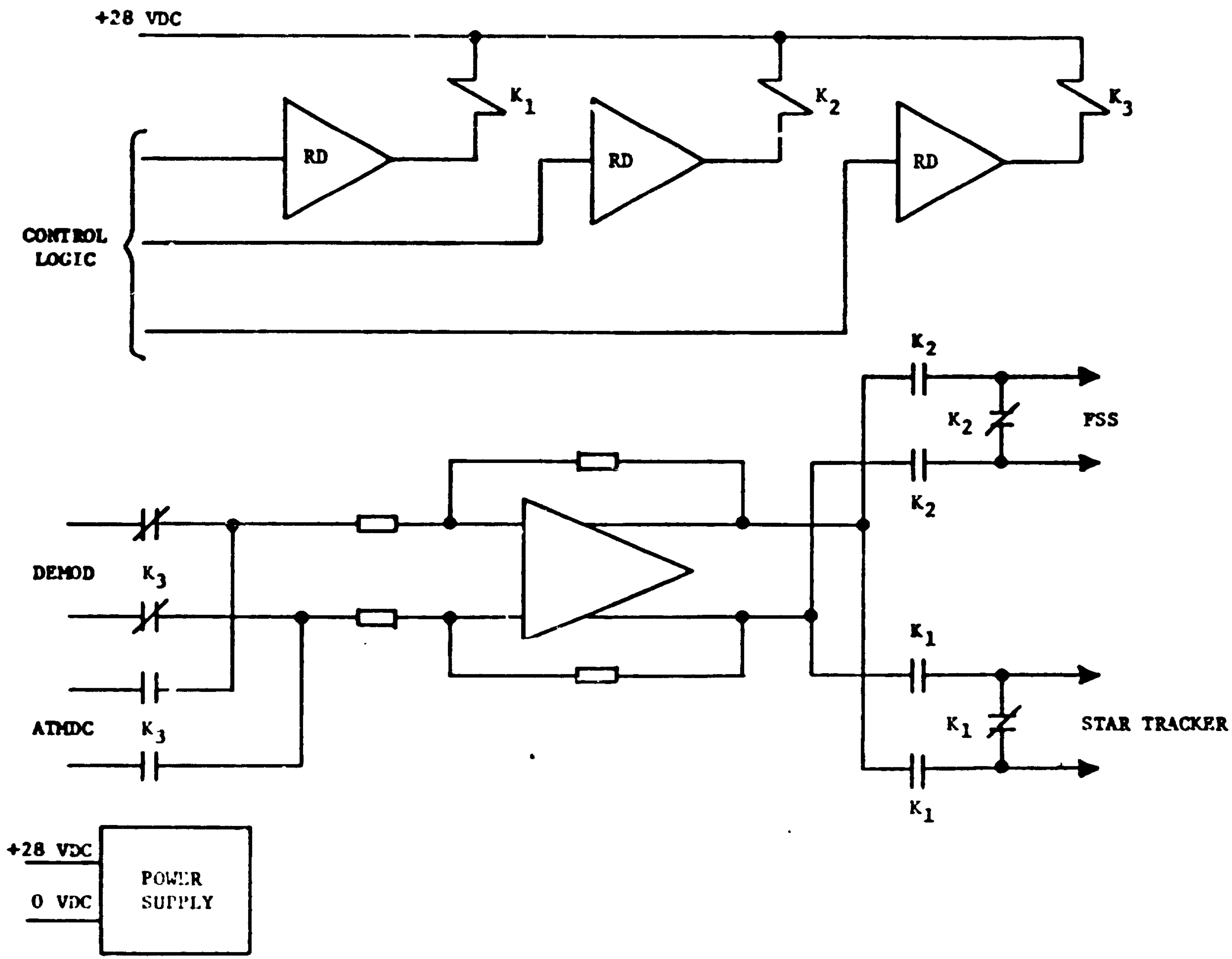


Figure 2.2.2-16. Buffer Amplifier

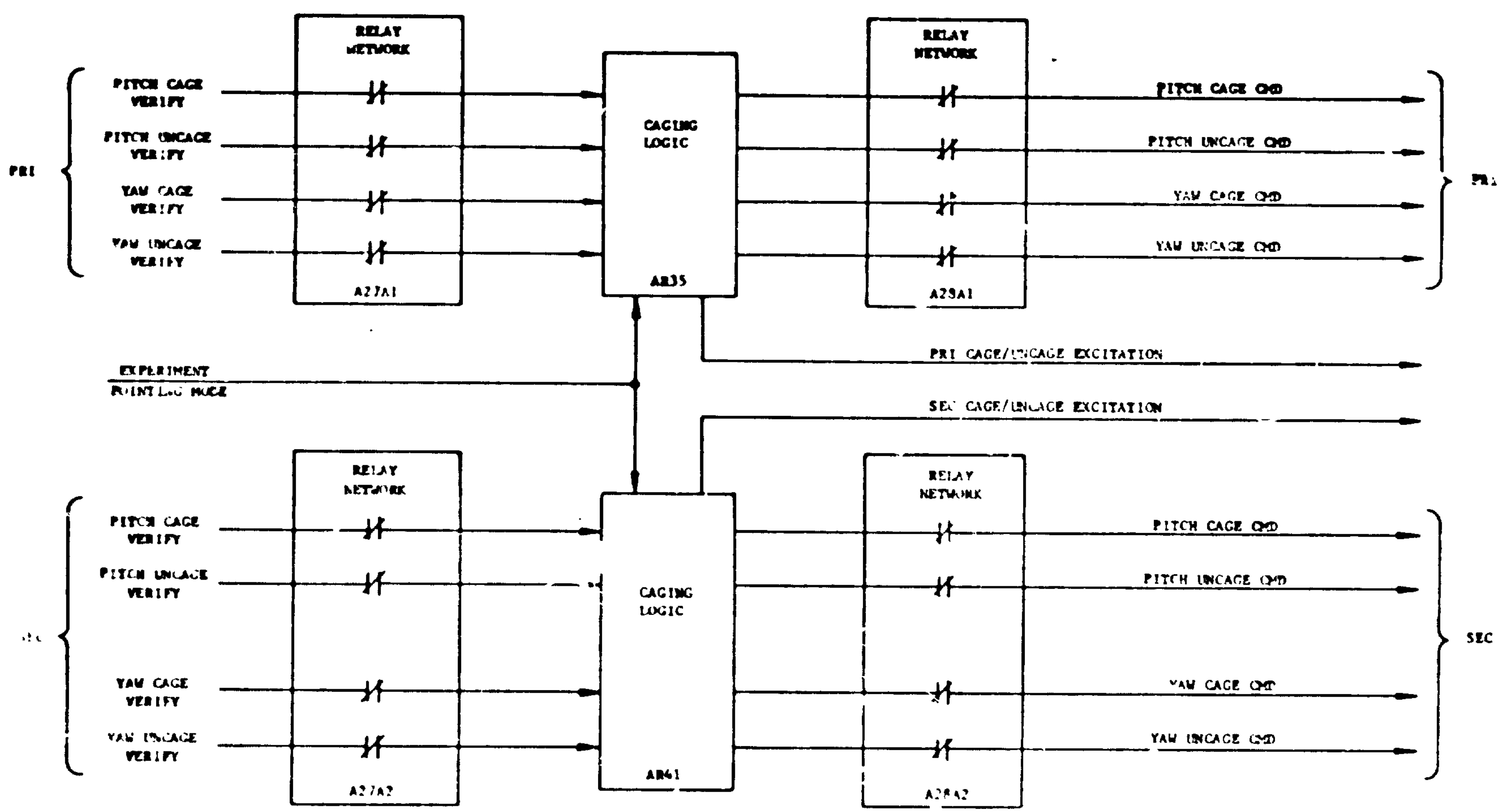


Figure 2.2.2-17. Orbital Caging Channels

AR35; the secondary caging logic is contained in AR41.

2.2.2.3.5.1 Caging Logic Electronics (AR35, AR41)

Only the primary pitch channel circuitry is shown in Figure 2.2.2-18. It consists of three amplifiers, two relays and two time delay units.

When the system is not operating in the EXP PTG mode, K_1 is activated by a cage verify signal; K_2 is activated by the interval +28 VDC bus voltage applied to A3. Therefore, the output signals to the pitch orbital lock are grounded.

When the system is switched to the EXP PTG mode, K_2 is released by the discrete signal applied through A_2 and A_3, thus applying an uncage command to the pitch orbital lock. When the uncaging process is completed, an uncage verify discrete signal will return K_2 to the ground position, while K_1 is held in the ground position by the EXP PTG discrete signal. When the discrete signal is removed, K_1 is released causing a cage command to be given and the spar is returned to the zero cage position, where it is locked. The time delay units allow sufficient time (5 seconds) for the cage/uncage operation to be completed before reversing the logic.

2.2.2.4 Physical Characteristics of the EPEA

The outline dimensions of the EPEA are as shown on Figure 2.2.2-19. Figures 2.2.2-20 and 2.2.2-21 are photographs of an EPEA; Bendix P/N 2124900-9,

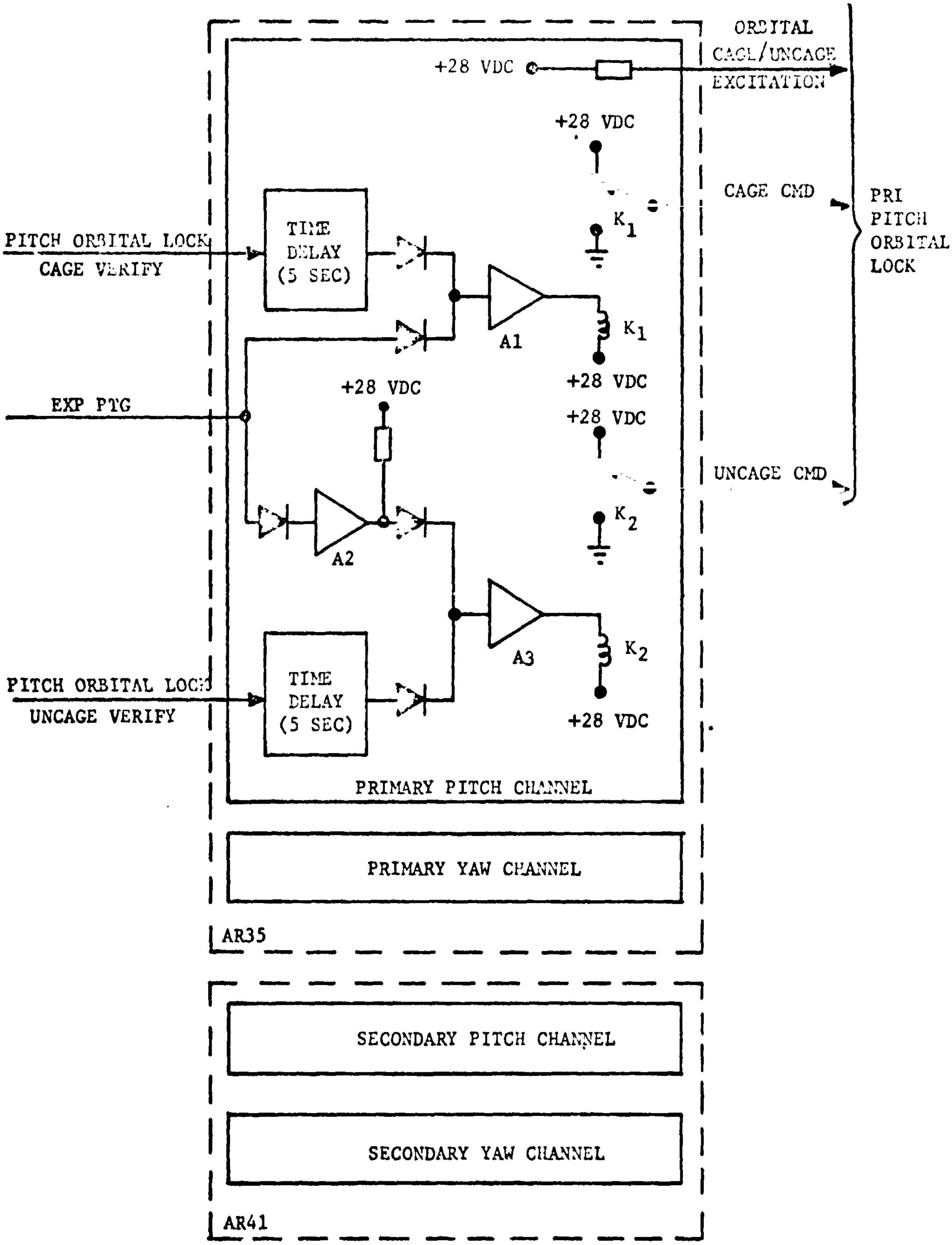


Figure 2.2.2-18. Caging Logic Block Diagram

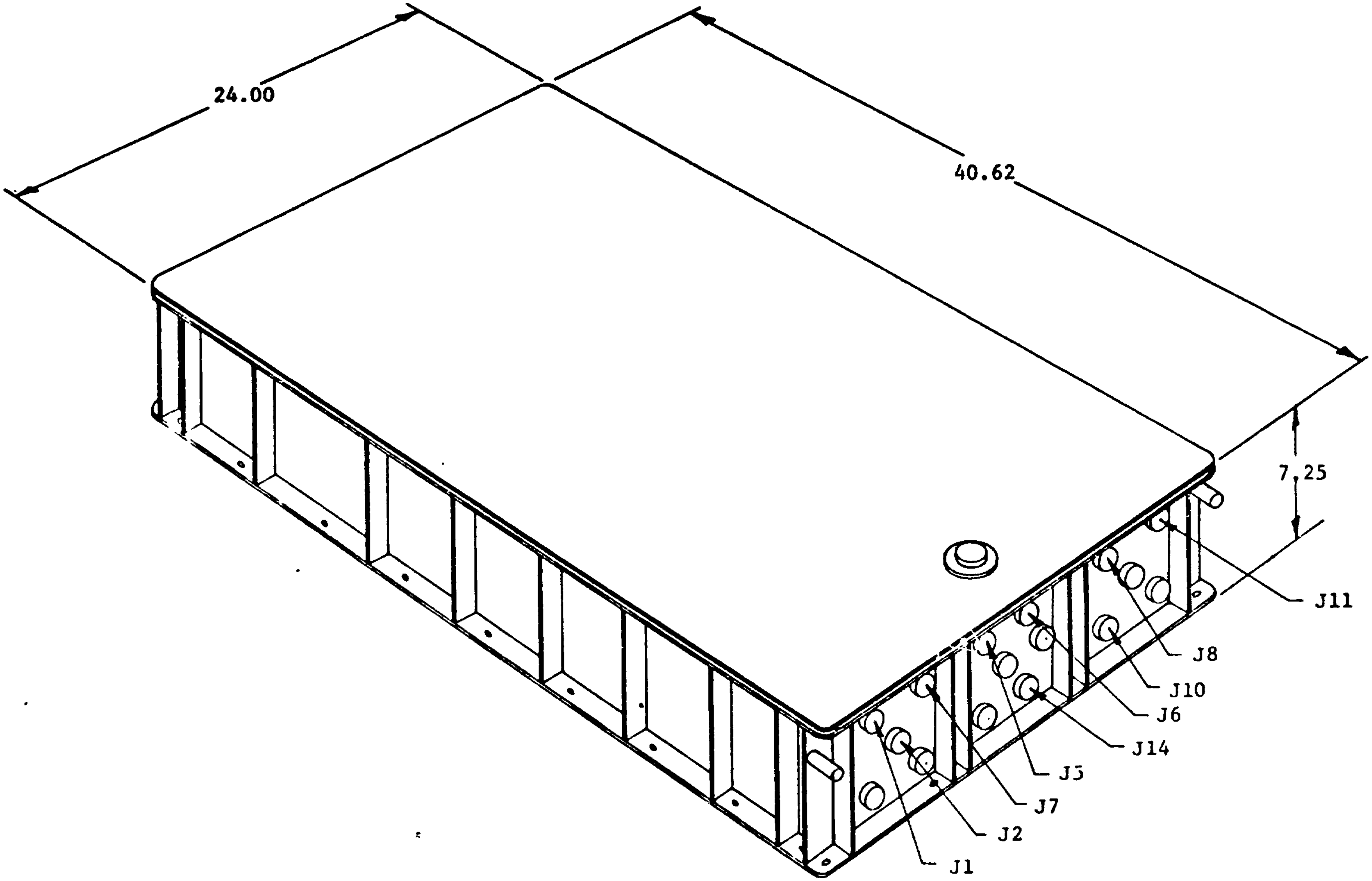
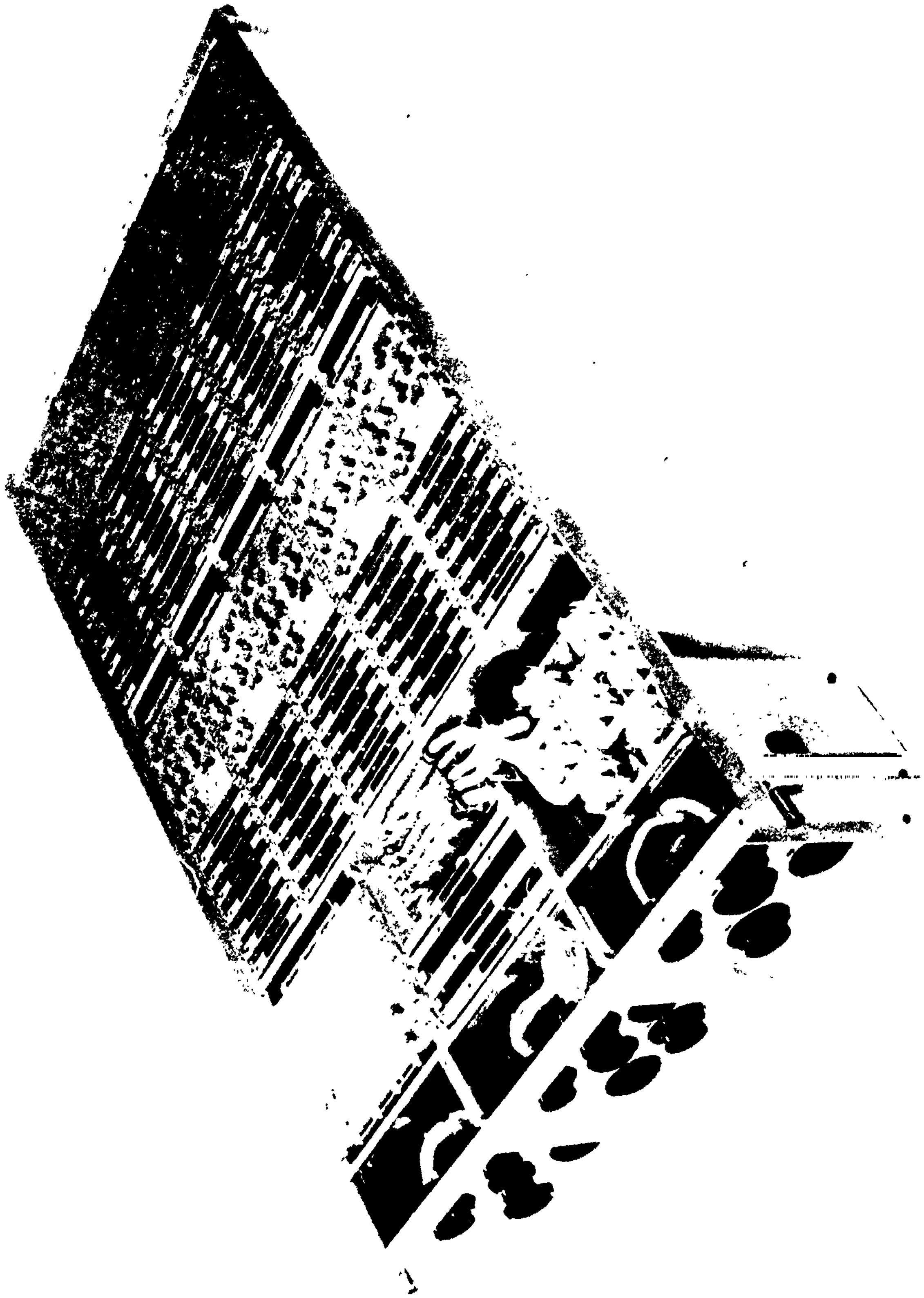
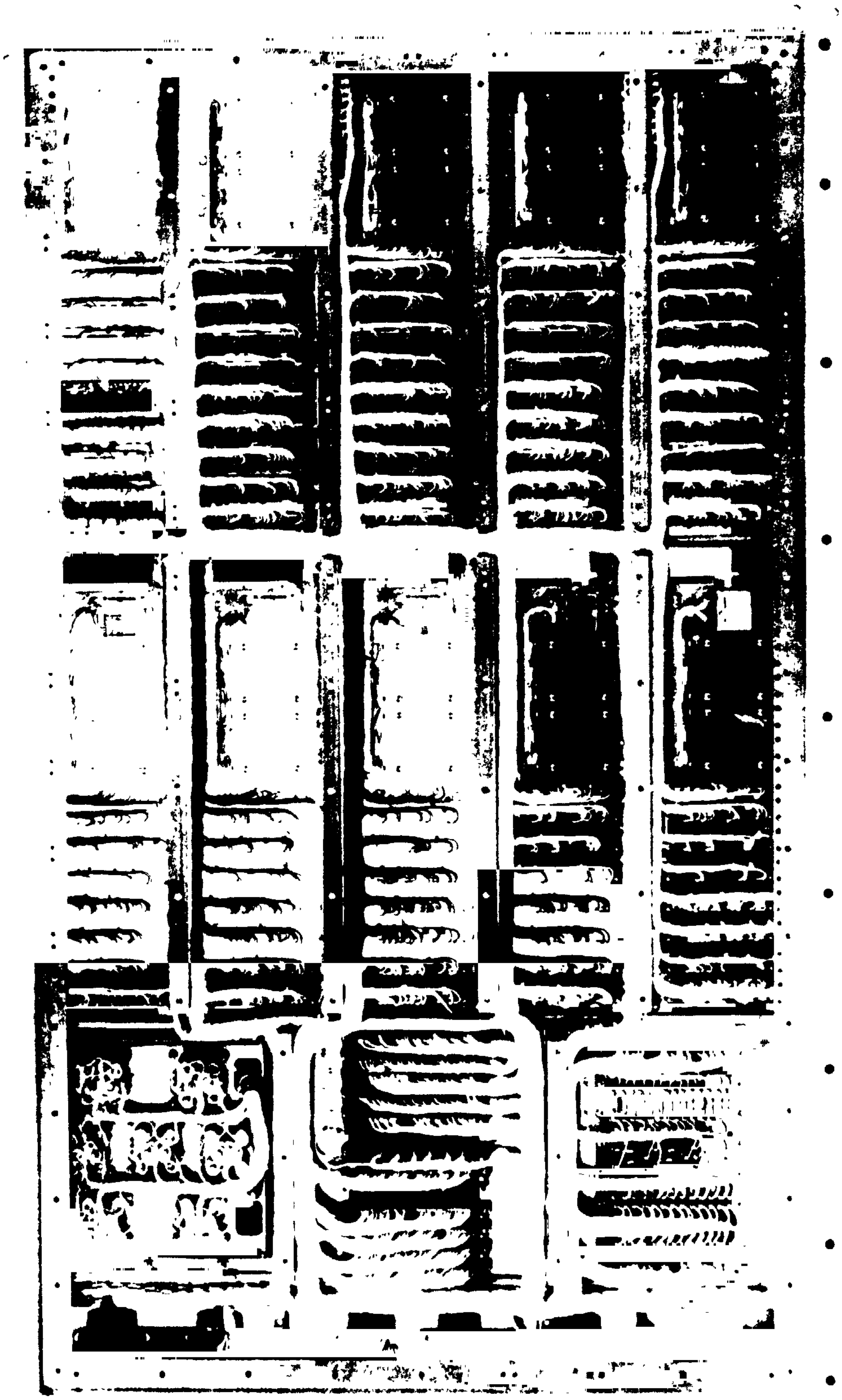


Figure 2.2.2-19. Experiment Pointing Electronics Assembly



EPEA TOP VIEW
FIGURE 2.2.2-20



EPEA BOTTOM VIEW
FIGURE 2.2.2-21

NASA 50M38500. The EPEA weight is approximately 185 lbs and its power dissipation is 69 watts nominal and 418 watts peak.

2.2.2.5 Key Defining Documents

a. CP-2124900-9A; CEI Specification Part I - Performance and Design Requirements - ATM EPEA.

b. CP-2124900-9; CEI Specification Part II - Product Configuration and Acceptance Test Requirements - ATM EPEA

c. 2124450 (GTSP); Final Test Specification and Procedure for the ATM EPEA

d. 2124901 Overall Schematic

e. 2124904 Pin Function Diagram

f. 2124890 Chassis Assembly

g. 2124902 Wiring Harness Diagram

h. 2124776 Family Tree

i. 2124905 EPC Loop Phasing Diagrams, Pitch and Yaw

j. 2124906 EPC Loop Phasing Diagrams, Roll

2.3 EPEA QUALIFICATION

2.3.1 Introduction

The EPEA was successfully qualification tested through the conduct of testing by Bendix and by MSFC. The total qualification effort is documented in a six volume report entitled "Qualification Test Report for the ATM EPEA" (MT-15,732). The six volumes are as follows:

Vol. I	Text and Summary dated April 27, 1972
Vol. II	Discrepancy Reports and Analysis dated April 25, 1972
Vol. III	Environmental Test Data dated April 15, 1972
Vol. IV	Raw Test Data, Tests 1-6 dated Feb. 15, 1972
Vol. V	Raw Test Data, Tests 7-15 dated Feb. 15, 1972
Vol. VI	Raw Test Data, Tests 16-21 dated Feb. 15, 1972

The unit used for qualification was of flight configuration and is designated as serial number 003 ATM EPEA Bendix P/N 2124900-9 (NASA 50M38500). The qualification test time period was from August 1971 to December 1971.

2.3.2 DESCRIPTION OF ENVIRONMENTAL TESTS

Environmental tests can be divided into two categories: operating and non-operating. During operating tests, the EPEA was subjected to constraints simulating the orbit environment. The non-operating tests were performed in conditions simulating transportation and launch conditions.

2.3.2.1 Humidity (EPEA Non-Operating)

The humidity chamber shall be vented to the atmosphere and a maximum air velocity within the test chamber area shall be 150 feet per minute. If a wet bulb is used, air flow at the bulb shall be 900 feet per minute minimum. Only distilled or deionized water with a pH value between 6.5 and 7.5 at 25°C shall be used.

The EPEA shall be placed in the test chamber and subjected to the following humidity-temperature cycle:

a) Maintain chamber for 6 hours at 37.2°C and 50 percent relative humidity
b) Over a 5-hour period, gradually reduce air temperature to 24.4°C with relative humidity increasing to 95 to 100 percent.
c) Over an 8-hour period, gradually reduce air temperature to 21.1°C with a release of water condensate, and with the relative humidity of the chamber remaining at 95 to 100 percent.
d) Over a 4-hour period, increase air temperature to 37.2°C with a resultant decrease in relative humidity to 41 percent.
e) Over a 1-hour period, with temper_ture at 37.2°C, increase relative humidity to 50 percent.
f) The preceding steps constitute one humidity cycle. This cycle shall be repeated a minimum of five times.

2.3.2.2 A functional test shall be in process within 1 hour after removal from the chamber. The altitude and thermal vacuum tests shall be performed after the unit has been allowed to dry at ambient lab conditions for a minimum amount of time but not to exceed 5 days.
(See Note 3 of test requirements in Procedure 50M38506.)

Altitude (EPEA Operating)

This test shall be performed in conjunction with and as the first portion of the thermal vacuum test.

The EPEA will require thermal control during this test and will be mounted in the thermal vacuum chamber (cold case) on teflon standoffs and on 50 layers of aluminized mylar.
The procedure outlined in 50M02408 shall be used for this test.

This test will include a continuous monitoring of power supply current to determine if arcing occurs, and a functional test during pumpdown.

2.3.2.3 Thermal Vacuum (EPEA Operating)

The bottom of the EPEA unit under test will be covered with approximately 50 layers of aluminized mylar. Standoff insulators will be of teflon. A thermocouple junction will be located beneath the head of a bolt at each of the EPEA normal mounting pads and on the chamber shroud. The shroud will be considered as the sink.

The low temperature portion of the thermal vacuum test will be run first, and then the high temperature as follows:

a) Low temperature -

The chamber shall be evacuated to a pressure of 8.5×10^{-5} torr. The shroud temperature will be lowered gradually until the EPEA temperature, as indicated by the average of the thermocouple junctions located at the mounting pads, reaches -55°C. The EPEA will be powered up to its operating mode upon approaching the temperature of -55°C. The EPEA will remain in an operating mode for 6 hours. During this time, the shroud temperature will be maintained as required to maintain the EPEA temperature at -55°C. At the end of the 6-hour stabilization period and while maintaining that temperature, a Functional Test will be performed. The EPEA will then be returned to ambient lab temperature.

b) High temperature -

The thermal vacuum test installation shall be installed as for the cold case except that the 50 layers of aluminized mylar shall be under the teflon standoffs and not against the bottom of the EPEA. The chamber will be evacuated to a pressure of 8.5×10^{-5} torr. The EPEA unit will then be powered-up and the shroud temperature will be increased gradually until the EPEA reaches a temperature of +74°C. The EPEA will remain in its operating mode and its temperature allowed to stabilize at +74°C. The shroud temperature will be maintained, as required, to maintain the EPEA at +74°C. The EPEA will be allowed to stabilize at the these conditions for a period of 8 hours. At the end of the 8-hour stabilization period and while maintaining that temperature, a Functional Test will be performed. Upon completion of the Functional Test, the EPEA will be powered off and returned to +25°C.

The chamber pumping system will then be shut down and the chamber backfilled with dry gaseous nitrogen to existing atmospheric pressure. An Operational Test will then be performed when the existing environment has reached stabilization.

2.3.2.4 Outgassing (EPEA Operating)

MSFC Document 50M02478 shall be used in the performance of the outgassing test.

2.3.2.5 Acceleration (EPEA Non-Operating)

The EPEA shall be mounted on a centrifuge by use of its normal mounting provisions.

The unit shall be accelerated to 10 g when measured at the geometric center of the unit. All parts of the units are to experience at least 85 percent of the specified g level.

The EPEA shall be tested in each of the three major axes and in both directions of each axis. Each of these six tests shall last 3 minutes minimum.

An operational test and visual inspection shall be made after completion of acceleration tests.

2.3.2.6 ATM Power Switching Transient (EPEA Operating)

Specification 50M02477 shall be used in the performance of this test.

The following procedure shall be used in checking the ATM EPEA:

Set the transient generator to the first test level to be used in the test.

Command the EPEA to its operating mode. Allow the EPEA to operate with the test transient applied for 10 minutes monitoring the torquer amplifier output signals. No extraneous signals above ±10 milliamperes peak shall be allowed.

Repeat the preceding procedure for each of the different test transient levels required in the ATM power transient test in Specification 50M02477.

The EPEA internal power bus voltage shall be monitored and recorded. No voltage transient shall increase the 28-volt bus to above 36 volts.

A functional test shall be performed after the ATM power switching transient test to insure that the EPEA has experienced no permanent damage from the expected electrical system disturbances.

2.3.2.7 Electromagnetic Interference (EPEA Operating)

The electromagnetic interference test shall be performed on the EPEA to insure that it is compatible with all electrical/electronic equipment in the system.

There are basically three tests that will be performed in this category:

a) A test to be performed to establish if the test item generates signals in the radio frequency range.
b) A test to establish if the test item will pass radio frequencies back through its input sources.
c) A test to establish whether or not the performance of the test item is degraded or distorted due to the reception of radio frequencies.

In the performance of this test, the interfacing cables will also be included so that transmission between cables may be checked. These tests shall be conducted in compliance with paragraphs 4.3.1, 4.3.2, and 4.3.4 as defined in MIL-I-6181D. The EPEA shall meet the requirements of Plan 50M12725. No visual inspection is required after this test.

2.3.2.8 Acoustic Noise (EPEA Operating)

The EPEA shall be mounted in a reverberation chamber in such a manner as to not unduly interfere with the test (see MIL-STD-810 - Method 515, paragraph 3.5.1, except that all natural resonances of the suspension should be below 10Hz). The sound pressure levels and duration of the acoustical noise is given in Appendix E of MSFC Document 50M02408, Revision D.

The initial setup shall be done with sound levels 12 db below those of the test. The setup shall be done in as short a time as practical to minimize any possibility of damage to the EPEA.

The noise level shall be increased to the specified level and left on for the specified time. Both tests in Appendix E of 50M02408, Revision D, shall be carried out.

2.3.2.9 High Temperature (EPEA Operating)

The EPEA shall be wired for normal operation and placed in the test chamber. The temperature will be raised to 85°C, stabilized, and the test item soaked for a period of 48 hours. The EPEA will be operating during this time and the power supply current will be monitored and recorded.

Upon completion of this soak period, the temperature will be lowered to 74°C and stabilized for 4 hours. An operational test will then be performed on the test item. Upon completion of this step, the temperature will be lowered to 25°C, allowed to stabilize, and a functional test will be performed. The results of this test will be compared with the results of the previous operational test. A visual inspection of the test item will complete the high temperature test.

2.3.2.10 Low Temperature (EPEA Operating)

The EPEA shall be wired with connectors from the test equipment and placed in the cold chamber. The temperature will be lowered to -55°C and held at that temperature for a period of 4 hours. The EPEA will not be operating during this period. At the end of this period, the EPEA will be powered up and a functional test will be made at this low temperature. The temperature will then be raised to -40°C, allowed to stabilize, and an operational test performed. Upon completion of this test, the temperature will be raised to 25°C, allowed to stabilize, and an operational test performed. The results of this test will be compared with the results of the previous operational test. If results are different, these differences will be noted in the test report.

2.3.2.11 Thermal Shock (EPEA Non-Operating)

The EPEA shall be mounted on a low heat conductive material, ao as to prevent a sudden heat transfer from the surface of chamber, and then placed in the test chamber whose temperature will be raised to 74°C. This temperature will be maintained for a period of 4 hours at the end of which the test item will be transferred to a cold chamber whose temperature will be at -40°C. The EPEA will be exposed to this temperature for 4 hours. At the end of this period, the EPEA will be transferred to the oven at 74°C. This constitutes one cycle. The test consists of three continuous cycles. At the conclusion of the last cycle, the EPEA will be stabilized at 25°C and an operational test performed. Completion of the temperature shock test will consist of a visual inspection of the EPEA.

2.3.2.12 Vibration (EPEA Operating)

The EPEA shall be mounted on a vibration plate in a manner simulating its mounting on the ATM during flight. Sinusoidal and random vibration shall be completed along one axis before proceeding to another axis. Test procedure and levels follow:

a) Vehicle dynamics criteria (5 to 30 Hz at 3 octaves per minute):

1. Lateral axes

5 to 12 Hz at 0.20 inch DAD
12 to 30 Hz at 1.5g peak

2. Flight axis

5 to 13 Hz at 0.29 inch DAD
13 to 30 Hz at 2.5g peak

b) Sine evaluation criteria (20 to 2,000 Hz at 1 octave per minute):

1. 20 to 90 Hz at 0.0036 inch DAD
90 to 2,000 Hz at 1.5 g's peak

c) High Level Random Criteria (1 minute per axis):

20 Hz at 0.00020 g^2/Hz
20 to 90 Hz at +9 db/oct
90 to 150 Hz at 0.033 g^2/Hz
150 to 285 Hz at +9 db/oct
285 to 500 Hz at 0.22 g^2/Hz
500 to 2,000 Hz at -12 db/oct
2,000 Hz at 0.00066 g^2/Hz Composite - 10.0 g rms

d) Low Level Random Criteria (4 minutes per axis)

20 Hz at 0.000078 g^2/Hz
20 to 90 Hz at +9 db/oct
90 to 150 Hz at 0.0071 g^2/Hz
150 to 285 Hz at +9 db/oct
285 to 500 Hz at 0.046 g^2/Hz
500 to 2,000 Hz at -12 db/oct
2,000 Hz at 0.00018 g^2/Hz Composite - 4.6 g rms

The state of all required analog output commands and signals shall be monitored on a multichannel chart recorder.

After completion of the vibration test, a complete Final Acceptance Test shall be performed in an ambient environment. When this is completed, the EPEA shall be disassembled for a complete visual inspection of each module and of the chassis for structural damages.

2.3.3 KEY APPLICABLE DOCUMENTS

The following documents, of exact issue shown, were a part of the qualification test plan and program, and were referenced, as applicable, in the performance of the test procedure.

a)	50M38502	Environmental Performance Specification for the ATM Experiment Pointing Electronics Assembly
b)	50M38506	Environmental Test Procedure for ATM Experiment Pointing Electronics Assembly
c)	50M38503	Acceptance Test Specification for the ATM/EPEA
d)	50M02408, Rev. D	Environmental Design and Qualification Test Criteria for Apollo Telescope Mount Components
e)	50M02478	Component and Subsystem Thermal Vacuum Outgassing Specification for ATM
f)	50M12725	ATM Electromagnetic Compatibility Control Plan
g)	50M02477	ATM Circuit Transient Specification

h)	MSFC Form 2960	Astrionics Laboratory Environmental Test Data Summary
i)	MIL-STD-810B	Environmental Test Methods
j)	MIL-I-6181D	Interference Control Requirements, Aircraft Equipment
k)	AMD 8000.4 Annex A	Astrionics Laboratory Management Directive
l)	MT-15,661 Rev. C	Qualification Test Plan for the ATM Experiment Pointing Electronics Assembly
m)	MT-15,662 Rev. C	Qualification Test Procedure for the ATM Experiment Pointing Electronics Assembly
n)	MT-15,708	Technical Description, ATM/EPEA
	2124450(GTSP)	Final Test Specification and Procedure for the ATM Experiment Pointing Electronics Assembly (ATM/EPEA)
o)	2124453(GTSP)	Operational Test Specification and Procedure for the ATM/EPEA Qualification Unit
p)	2124454(GTSP)	Functional Test Specification and Procedure for the ATM/EPEA Qualification Unit

2.4 RELIABILITY

Report MT 14,694 (Revision B), "Failure Mode, Effects, and Criticality Analysis of the ATM EPEA", November 11, ... combines a Reliability Prediction, Failure Mode and Effects Analysis, and Criticality Analysis.

The results of these analyses are as follows:

I. Prediction

a. Mean Time Between Failures = 8,085 hours (based upon total EPEA failure rate of 123.692 x 10^{-6} parts per hour)

b. Probability of Survival for a 240-day mission - 0.99932 (based upon a net failure rate of 0.11822 x 10^{-6} parts per hour)

The total failure rate is equal to the sum of the failure rates of all the parts contained in the EPEA. The net failure rate is equal to the total failure rate less the failure rates associated with non-critical failure modes, and replacing the sum of the failure rates of the circuits which form redundant configurations with the failure rates of the redundant configurations.

II. Criticality Analysis

The criticality of the EPEA, for a 240-day mission is 680.96 (based upon the EPEAs net failure rate).

III. Failure Mode and Effects Analysis

The above referenced report contains an FMEA section of more than 100 pages, which details the failure modes of the EPEAs constituent modules, and their effects on the EPEA and the ATM.

IV Single-Point Failures

Except for non-critical functions (associated with telemetry, test, etc.) the EPEA has no single point failures due to redundancy on the module and on the part level.